

# Research and Development



## Highlights 2003



U.S. Department of Transportation  
**Federal Aviation Administration**

**Airport and Aircraft Safety R&D Division**

William J. Hughes Technical Center  
Atlantic City International Airport, New Jersey 08405

## FOREWORD

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As the nation's premier research organization for aviation technology, the Federal Aviation Administration's (FAA) aircraft research and development (R&D) program has made significant contributions to assure the safety, efficiency, and cost-effectiveness of the national aviation system. Today that system is under heavy pressure to keep pace with rising traffic demand, needs for essential safety improvements, airspace user requirements for more flexible and efficient air traffic management operations, and demands for further mitigation of the environmental impacts of aircraft operations. To meet these future challenges, the FAA employs a comprehensive research, engineering, and development program that assures all available resources remain customer-focused and targeted on the highest priority activities.

The fundamental mission of the FAA is to foster a safe and efficient air transportation system. With respect to safety, the FAA's goal is to establish an operating environment that promotes an error-free system that produces no accidents or fatalities. The mission of the Airport and Aircraft Safety R&D Program is:

*To provide a safe global air transportation system by developing technology, technical information, tools, standards, and practices to promote the safe operation of the civil aircraft fleet.*

This report contains highlights of the major accomplishments and applications that have been made by Airport and Aircraft Safety researchers and by our university, industry, and government colleagues during the past year. The highlights illustrate both the broad range of R&D activities supported by the FAA and the contributions of this work in maintaining the safety and efficiency of the national aerospace system. The report also describes some of the Division's most important research and testing facilities, considered to be some of the most scientifically advanced in the world. For further information regarding this report, contact Mr. Jason McGlynn, [jason.mcglynn@faa.gov](mailto:jason.mcglynn@faa.gov), Technical Publications Editor, AAR-400, FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405, (609) 485-6420.



Chris C. Seher  
Director

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# Structural Integrity



## Operational Loads Monitoring

Title 14 Code of Federal Regulations (CFR) Part 23 Airworthiness Standards are replete with loads criteria much of which were generated prior to deregulation and, in some cases, prior to the design of both wide-body and fly-by-wire civil aircraft. With the existence of new technology, newer operating rules and practices, and the anticipation of double the air traffic within 10 years, there is a need to develop and implement a system to continuously validate and update the operational flight and ground loads airworthiness certification standards based on actual measured usage.

The Federal Aviation Administration (FAA) has an ongoing Operational Loads Monitoring Program, which includes both flight and landing loads data collection on civil transport aircraft, as shown in figure 1.

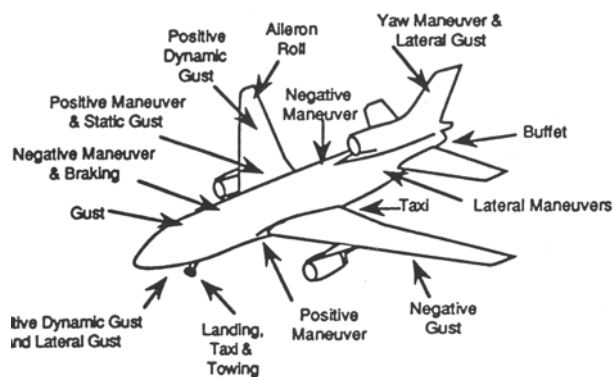


Figure 1. Typical Aircraft Loads

The output from the Operational Loads Monitoring research provides the technical basis for airframe certification requirements. The research independently assesses the original equipment manufacturers (OEM) design assumptions and aircraft usage analysis. This is a fundamental element of the FAA's regulatory and certification process and is an essential input to

confirming the continued safety and airworthiness of the civil transport fleet. The research provides the opportunity to identify operational problems in a proactive manner.

Data from digital flight data recorders (figure 2) are acquired, processed, and analyzed and are published in formal FAA reports. Thirty formal loads-related FAA technical reports have been published along with a significant number of technical papers.

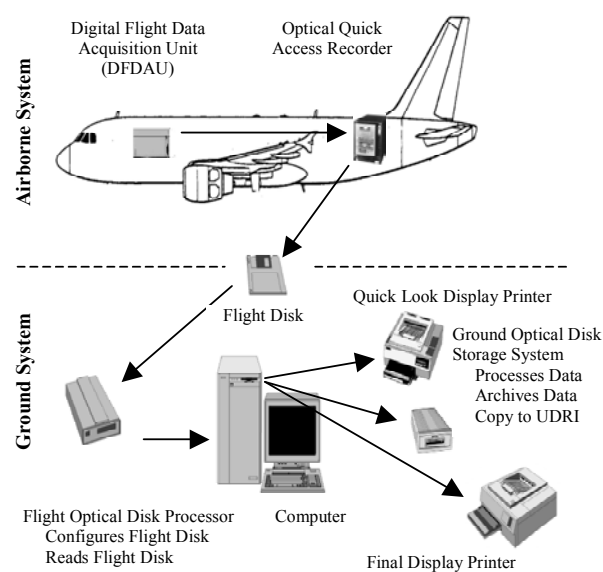


Figure 2. Optical Disc Flight Data Flow

The FAA Operational Loads Monitoring team provided specialized operational loads data and analysis for the Aviation Rulemaking Advisory Committee (ARAC) to develop recommendations for the certification criteria for the A380 airplane, 14 CFR Part 25.495, Turning.

The research resulted in the publication of "Side Load Factor Statistics From Commercial Aircraft Ground Operations," DOT/FAA/AR-02/129, Tipps, D., et al., January 2003. Presented in the report are analyses and statistical summaries of

landing and ground operations data to provide the FAA with a technical basis for assessing the suitability of the 0.5-g lateral acceleration criteria specified in 14 CFR Part 25.495 for turning, figure 3. The data

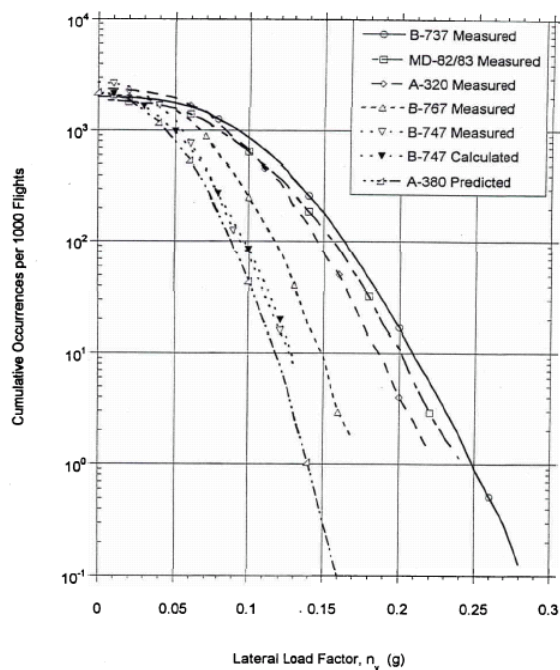


Figure 3. Comparison of Measured and Calculated Cumulative Frequency of Ground Turning Lateral Load Factor, Taxi-in

represent 1037 flights, 1039 flights, and 1361 flights of B737-400, B767-200ER, and B747-400 aircraft, respectively. Included is statistical information on vertical and lateral accelerations, yaw angles, ground speeds, and gross weights experienced during touchdown and ground operations. Ground-turning lateral acceleration data were used in the development of a normalization procedure to allow prediction of lateral load factors due to ground turning on other aircraft. While the data contained in the report might indicate that the 14 CFR Part 25.495 may be conservative at the 0.5-g level, when one considers that 14 CFR Part

25.495 takes into consideration asymmetric gear loading for both dry and highly slippery conditions, the retention of the traditional 0.5-g value may well be appropriate. The results of this study clearly indicate, however, that the lateral loads experienced by the larger and heavier transport jets during ground turns are substantially less than those of the smaller jet transports.

Statistical data are presented on the aircraft's usage, flight and ground loads data, and systems operations in the technical report "Statistical Loads Data for Bombardier CRJ-100 Aircraft in Commercial Operations," DOT/FAA/AR-03/44, Rustenberg, J., June 2003. The data presented in the report provide information about the accelerations, speeds, altitudes, flight duration and distance, gross weights, speed brake and spoiler cycles, thrust reverser usage, and gust velocities encountered by the CRJ-100 airplane (figure 4) in actual operational usage. The statistical data provided the FAA, aircraft manufacturers, and the operating airline with the information that is needed to assess how the CRJ-100 is actually being used in operational service versus its original design or intended usage. The FAA plans to (1) evaluate existing structural certification criteria, (2) improve requirements for the design, evaluation, and substantiation of existing aircraft, and (3) establish design criteria for future generations of new aircraft using the data. Aircraft manufacturers use the data to assess the aircraft's structural integrity by comparing the actual in-service usage of the CRJ-100 versus its originally intended design usage. While current program research efforts are tailored primarily to support the FAA regulatory community, the data can also provide the aircraft operators with some valuable insight into how their aircraft and aircraft systems are being used during normal flight and ground operations.



Figure 4. CRJ-100 Airplane

The FAA William J. Hughes Technical Center hosted a Gust Specialists Seminar in May 2003 to review and document the Statistical Discrete Gust (SDG) Method, which is used as an alternative procedure for estimating severe gust and turbulence loads. The seminar was the last in a series of seminars going back to 1986 when an international team of specialists, convened by the FAA, met approximately annually to re-evaluate the gust criteria for future generations of commercial transport aircraft. The goals of this international ad hoc committee have been to reduce the number of design criteria to be met and to recommend a design method with the ability to handle advanced technologies such as active controls and gust load alleviation.

The SDG method provides a specification, which accounts for the non-Gaussian statistical structure of the more intense

turbulence fluctuations, and the manner in which these interact with the dynamic response of a flexible aircraft. SDG can be interpreted as a generalization of the existing tuned Isolated Discrete Gust (IDG) model to take account of tuning to gust patterns of different shapes. SDG is also expressed in a statistical format that parallels that of the Power-Spectral-Density method, being applicable in both Mission Analysis and Design Envelope forms.

The SDG method has been identified as the only existing method that can handle discrete gust events and relatively continuous turbulence and, moreover, can be used to evaluate highly nonlinear systems. The SDG has not been recommended by the Gust Specialists Committee for consideration as a revised airworthiness requirement, perhaps, at least in part, as a result of perceived computational complexity. However, the SDG remains the only existing method with the potential to meet the goals of the international ad hoc committee.

Additional information can be found at [http://aar400.tc.faa.gov/Programs/Aging Aircraft/airbornedata/index.htm](http://aar400.tc.faa.gov/Programs/AgingAircraft/airbornedata/index.htm).

Thomas DeFiore, AAR-480, (609) 485-5009

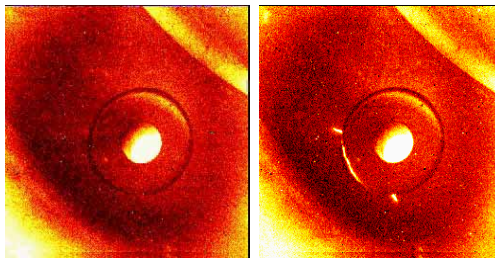
## Development of Sonic Infrared Imaging (Thermosonics) for Aircraft Structures

A new nondestructive inspection (NDI) technique is being developed that combines sound energy and infrared (IR) imaging to detect frictional heating produced by cracks, delaminations, and disbonds that could be in aircraft structures. This technique, known as sonic IR imaging, or thermosonics, was first applied in 1999 by researchers at Wayne State University (WSU) who found that

short pulses of ultrasound (50 to 500 ms) at frequencies of 20 to 40 kHz could cause defects, such as cracks, in solid objects to heat up and become detectable to an IR camera. This patented technology offers both broad area inspection capability and high sensitivity to surface breaking and near-surface cracks.

As shown in figure 1(a), the IR image shows no visible cracks at a bolthole prior to ensonification. After ensonification of the same hole, the IR image, figure 1(b), clearly

shows radial cracks at the 6 and 9 o'clock positions and a circumferential crack between these points.



(a)

(b)

Figure 1. Crack Detection in an Aircraft Wheel Using Thermosonic Imaging (a) Before and (b) During Sound Excitation

Since 1999, research on the use of thermosonics for aircraft inspection has been funded at WSU by the FAA through its Airworthiness Assurance Center of Excellence as part of the National Aging Aircraft Research Program.

To date, several prototype systems have been developed. One system, located at the FAA Airworthiness Assurance NDI Validation Center (AANC) facility in Albuquerque, New Mexico, is shown in figure 2 inspecting a turbine disk. Other

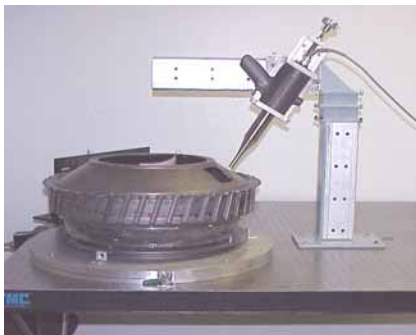


Figure 2. The FAA AANC Prototype Sonic IR System Setup to Inspect a Turbine Disk

experimental prototypes at WSU are shown in figures 3 and 4. Both of these figures

show ultrasonic sources that have been modified so that they can be held stable against an inspection surface during ensenification. The ultrasonic head, shown in figure 4, consists of a precisely tuned block of aluminum with three ultrasonic horns attached. These three horns vibrate simultaneously when the sound pulse is activated and provide three coherent sound sources rather than one source, as provided by the configuration shown in figure 3.



Figure 3. A Prototype Tripod Ultrasonic Source for Hand-Held Use on Aircraft



Figure 4. An Alternative Head for the Gun With Three Active Horns

Testing of these hand-held prototypes is ongoing, both in laboratories and in the field. Figure 5 shows the one-horn version being tested on the B737 test bed at the AANC.

Considerable progress is being made in the studies of this new NDI technique, although it should be recognized that this technology is still in its infancy and many fundamental issues still remain to be investigated and understood.



Figure 5. Testing a Hand-Held Prototype on the AANC B737

One such phenomenon recently discovered is called acoustic chaos. This phenomenon occurs in the test part when fractional multiples of the input excitation frequency

are present during ensonification. The relationship between this chaotic waveform and the sonic IR signal strength is not yet understood, although there are strong indications that the IR signal is much larger when acoustic chaos is present than when it is not. It is not yet clear how different frequency components of a sonic vibration contribute to the heating of the crack, how various sonic vibration modes contribute to relative displacements of crack surfaces, nor what are the overall optimal parameters for using the method in practice. Further study is ongoing to determine the origin of acoustic chaos and its effect on sonic IR heating.

Dave Galella, AAR-480, (609) 485-5784

## Automated Signal Analysis System for Aircraft Wheel Inspection

Aircraft wheels are subject to excessive stresses during landing and takeoff cycles. As such, it is a requirement to periodically inspect aircraft wheels to ensure their structural integrity. Eddy-current inspection is a widely used technique for inspecting aircraft wheels, since it is faster and easier to implement than other NDI techniques. The analysis of these eddy-current signals, however, generally depends on decisions of the human operator.

Funded as part of the FAA's Airworthiness Assurance Center of Excellence (AACE), Iowa State University, in collaboration with Northwest Airlines and ANDEC in Toronto, Canada, developed and implemented an automated signal analysis (ASA) system for aircraft eddy-current wheel inspections. The system is currently in beta-site testing at Delta Air Lines.

ASA systems are very useful for NDI, largely due to their ability for rapid analysis

of large amounts of data with enhanced accuracy and consistency. It minimizes human errors and probability of false calls while increasing the inspection speed and accuracy.

A schematic of the ASA wheel inspection system is shown in figure 1. The wheel is manually mounted on a rotating table. Information about the type of wheel is fed into the software to determine the scan plan. The eddy-current probe is held against the wheel and moved downward as the wheel is rotated, which ensures that 100 percent of the wheel is scanned. During each revolution, 2500 samples of data for each channel are collected. The data collected are then displayed on a time-based digital strip chart, an impedance plane, or a C-scan (plan view) image. The digital strip chart is superior to a paper strip chart since an operator can scan through and zoom in on signals and save the data for future use. The impedance plane is a tool used to obtain a visual representation of the shape and path of a defect in the wheel.

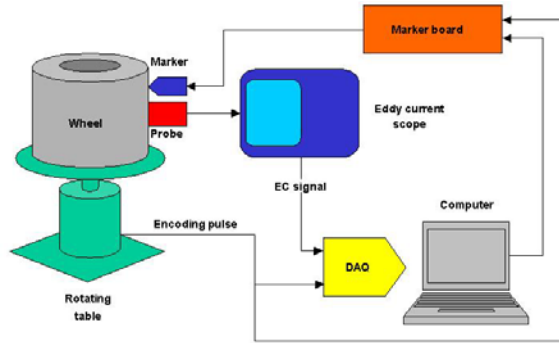


Figure 1. Schematic of the ASA System for Wheel Inspection

The ASA system developed here can image the C-scans as horizontal and vertical channels as well as functions of magnitude. These imaging tools enable the operator to analyze defects in the wheel graphically by scrolling over signals, such as holes, cracks, and notches, and viewing the raw signal in a window on the same screen, as shown in figure 2.

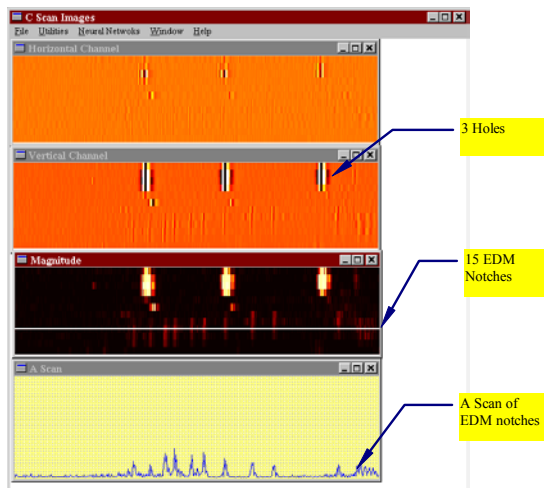


Figure 2. A Sample Image Window From a B747 Wheel Scan

The ASA system runs on any personal computer (PC) equipped with an input/output card and can control the functions of data acquisition and storage. The main window, shown in figure 3, has

three main buttons: Scan, Plot, and Image. To effectively analyze the signals while minimizing false alarms, the software uses a statistical method to calculate the appropriate threshold of data for different areas of the wheel, since different parts of the wheel have varying noise patterns. The program detects different areas of the wheel with a device known as an analog to digital converter card. This card assists the program's algorithm to determine a threshold value by the amount of data collected per rotation. The algorithm then determines the appropriate threshold level based on a predefined parameter for that portion of the wheel and the local amount of variation during a given time interval.

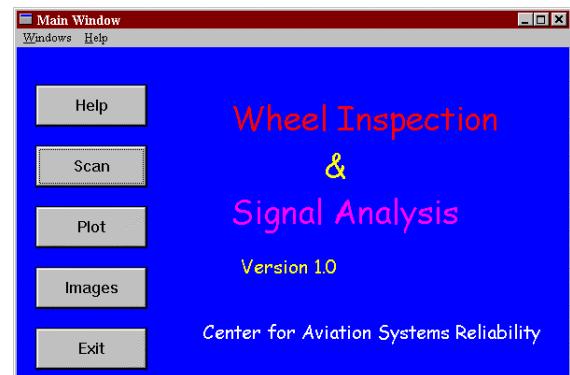


Figure 3. Main Window of the Wheel Inspection and Signal Analysis Software

During normal eddy-current inspections, most false alarms are caused by spikes of noise, which cause unusually large amplitudes in the signal. Using ASA, these false alarms are avoided because the spike signals only show up during one revolution of the wheel. Real defects in a wheel would show up during more than one consecutive revolution because they exist in three dimensions and it takes several revolutions to mark the locality. With the spatial correlation capability, the program can easily detect these occurrences.

The developed system uses software called Wheel Inspection and Signal Analysis to control a marker system to mark the locations of cracks in the wheel. The marker board receives inputs from the computer software via the parallel port and the encoder that is used to generate pulses for rotating the turntable. When the software detects a crack in the wheel, the marker pen is actuated to mark the circumferential position of the wheel during the following rotation. This enables the operator to physically locate the crack on the wheel for further detailed hand inspection.

The ASA system has been designed to help make the wheel inspection procedure faster and more efficient. The user can easily correlate a feature on the wheel to the electronic strip chart and also follow the formation of the complex impedance trajectory of this feature. C-scan images

allow visualization of feature size and location on the wheel, in contrast to paper strip charts, which require experience to recognize the number of flaws, flaw size, and location. Automatic retrieval of old data of the wheel, displays of difference images between the current and previous data, and image registration techniques all enhance the process of monitoring flaw initiation and growth. Using automatic signal classification to obtain online decisions about signal type and marking flaw locations on the wheel expedites the wheel inspection process and increases its reliability. The C-scan display helps visualize the wheel inspection data in an image form and also predicts the flaw size. Similar systems like this can be developed for other aircraft applications such as engine disk, impeller bores, and fuselage skin panels.

Cu Nguyen, AAR-480, (609) 485-6649

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## **Nondestructive Inspection of Composite Repairs**

In the aviation industry, structures repaired in the composite shop are generally cured in autoclaves, but repairs made on the aircraft may be done under more varied conditions and efforts must be made to ensure that the repaired composite components are mechanically sound.

Funded through the FAA Airworthiness Assurance Center of Excellence, Iowa State University undertook the development and implementation of two complementary NDI methods for composite repairs: Computer-Aided Tap Tester (CATT) and Air-Coupled Ultrasonic Testing (AC-UT).

The tap test needs only one-sided access but has a limited probing depth. The CATT, being a semiautomated and quantitative technique, can be used to map out the

interior conditions of a repaired part (see figure 1).

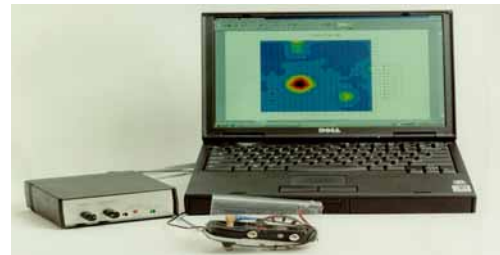


Figure 1. Computer-Aided Tap Tester

The AC-UT, shown in figure 2, is most effective in the transmission mode that inspects the entire thickness of the structure. The AC-UT technique, with its obvious advantage over water-coupled ultrasound, has the potential to be a practical NDI tool for airplane inspection. A primary objective of the current work is to correlate the interior conditions of a repair with the

features in the image from the CATT and AC-UT techniques.



Figure 2. Air-Coupled Ultrasonic Testing System

In this work, the CATT and the AC-UT system were applied to a number of composite repairs, both good and defective, on test panels and real components. The results were described and compared. One test panel containing a defective repair was destructively sectioned. The findings were compared to both the AC-UT and the CATT images.

After scanning with the CATT and the AC-UT system, the repair panel slated for destructive sectioning was cut with a diamond saw, polished, and examined under an optical microscope. Figure 3 shows the saw cut surface and the cross section of the repair.

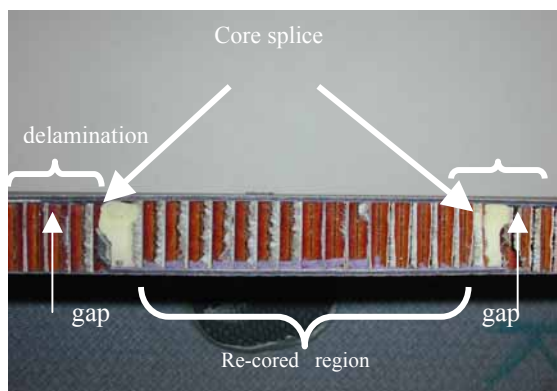


Figure 3. Cross Section of the Repaired Panel

The CATT and the AC-UT images were enlarged to true size and physically matched to the sectioned surface. These direct comparisons are shown in figure 4 for the CATT image and in figure 5 for the AC-UT image. In figures 4 and 5, the delamination matched very well with both images. Overall, the features in both the CATT and the AC-UT images corresponded quite well with the internal conditions of the repair.

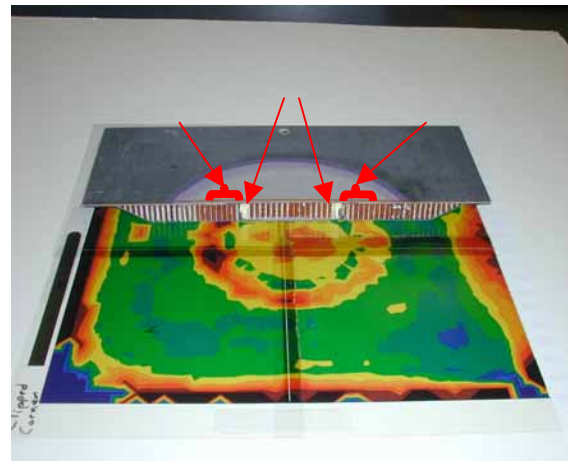


Figure 4. Correlation Between the Internal Conditions of Composite Repairs and its Image by the CATT

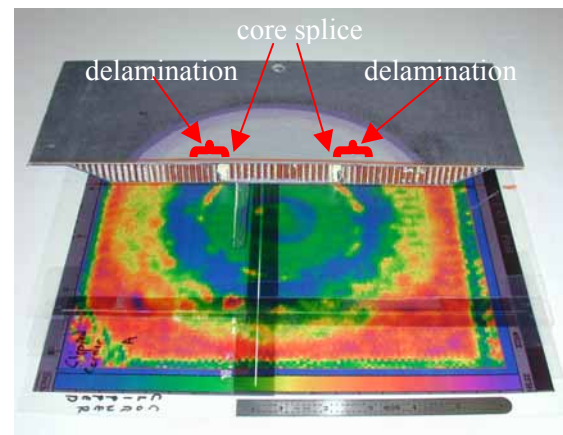


Figure 5. Correlation Between the Internal Conditions of Composite Repairs and its Image by the AC-UT System

Both the CATT and AC-UT systems were recently field tested at the United Airlines facility and at American Trans Air, both in Indianapolis, IN. The CATT system was used to image two hail-damaged components at United Airlines, a B737 trailing edge and an upper panel of an Airbus A320 horizontal stabilizer. The AC-UT system was used to inspect the B737 trailing edge by mounting the air-coupled

transducers on a yoke that was hand held. Results from these field tests correlated well with the sectioned repair and indicated that the imaging capabilities of both the CATT and AC-UT make these methods far more intuitive, accurate, and user-friendly than currently used methods such as coin tap and mechanical impedance analysis.

Cu Nguyen, AAR-480, (609) 485-6649

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## **Destructive Evaluation of Aging Small Airplanes**

By 2010, the average age of the fleet of small airplanes (~180,000 aircraft) will approach 40 years. However, little is known about the consequences of the aging process of small airplanes. Comprehensive teardown inspections provide critical information to determine the condition of high-time operational aircraft. Data developed from teardown inspections can be used to provide guidance for maintaining structural and systems integrity. Limited teardown inspections of large civil aircraft have been performed, which resulted in a limited and proprietary knowledge base. There is no such knowledge base for small airplanes. Therefore, FAA research of teardown investigation on small airplanes would provide an excellent opportunity to gain knowledge and insight required to support rulemaking, advisory circular preparation, and findings of compliance for small aircraft.

In September 2002, the FAA initiated a research project to evaluate two high-time commuter airplanes, both Cessna 402 models. The 402 was chosen because of its design commonality with several other commuter-class airplanes. The first aircraft, a 402A model built in 1969 with 19,700 flight hours, was primarily used for flying

tourists through the Grand Canyon. The second aircraft, a 402C model built in 1979 with 25,500 flight hours, was owned by Cape Air/Nantucket Airlines who flew commuter routes to islands in Massachusetts, Florida, the Virgin Islands, and Puerto Rico. The state of the structure and mechanical and electrical systems are being evaluated using destructive and nondestructive techniques. Specific observations made of the two aircraft selected for teardown investigation are being documented and generalized as applicable to the small airplane fleet in operation today.

The research is being conducted primarily at the National Institute for Aviation Research Aging Aircraft Research Laboratory at Wichita State University. The teardown evaluation involves two phases on each aircraft: an inspection phase and a teardown phase. In the inspection phase, over 100 visual inspections are performed on the airframe and aircraft systems along with detailed visual inspection of the aircraft wiring. Then, supplemental inspections are conducted on critical structural areas using NDI techniques such as visual, dye penetrant, magnetic particle, and eddy current. In addition, aircraft maintenance records, service bulletins, and airworthiness directives are being reviewed, including service difficulty and accident/incident reports for the Cessna 402 aircraft. The teardown phase includes disassembly of the

aircraft (figure 1), inspection of aircraft systems' components, investigation of advanced NDI methods (such as magneto optic imaging shown in figure 2), laboratory testing of aircraft wiring, detail disassembly of aircraft sections, and microscopic examination of critical structural areas in the airframe (figure 3).



Figure 1. Disassembly of a Cessna 402A



Figure 2. Magneto Optic Imaging



Figure 3. Microscopic Examination

Several industry participants are assisting with many aspects of the project. Cessna is providing technical and engineering support along with certified technicians to perform the supplemental inspections. Cessna's piston service center is providing service bulletins and service requirements applicable to the 402 aircraft. AAR-480 provided the 402A model, while Cape Air/Nantucket Airlines provided the 402C and technicians to support the inspection and disassembly of the aircraft. The FAA Airworthiness Assurance NDI Validation Center is participating in the program by monitoring the supplemental inspections and investigating advanced NDI methods that may be applicable to this type of commuter aircraft. The FAA Small Airplane Directorate and the Wichita Aircraft Certification Office are assisting in the review of service difficulty and accident/incident reports along with certification requirements for these aircraft.

The inspection phase for the Model 402A was completed in March 2003, and the teardown phase was completed in September 2003.

Michael Shiao, AAR-480, (609) 485-6638

## Damage Tolerance-Based Skin Repair Software

The effect of structural repairs on aircraft structural integrity is one of the critical issues that need to be addressed for the assurance of aircraft continuing airworthiness and operational safety. In addition, the Aging Airplane Safety Interim Final Rule requires the use of damage tolerance-based inspection programs on airplanes with multiple engines and ten or more passengers used in scheduled operations (operation within the state of Alaska is exempt) was published on December 6, 2002. To assist the small airplane industry in complying with this aging rule, an integrated design assessment tool, Repair Assessment Procedure and Integrated Designs for Commuters (RAPIDC), has been developed. RAPIDC is an automated static strength and damage tolerance analysis tool for skin repairs and antenna installations. It is a PC Windows-based software with user-friendly, point-and-click graphical user interface (GUI) features. It has an advisory system to provide repair guidelines as needed. An extensive material and fracture parameter database was also created for easy data access. RAPIDC Version 2.0 was released January 31, 2003, via the Internet at the following website <http://aar400.tc.faa.gov/Programs/AgingAircraft/Commuter/RAPID>.

The latest version includes a built-in finite element module (FEM), an automatic FEM mesh generator, a load spectrum generator, and static and damage tolerance analysis modules for fuselage skin repairs and antenna installations. The built-in FEM is used to determine fastener load transfer of mechanically fastened multiple layers. An automatic mesh generator eases users' effort for model preparation. Typical fuselage skin repairs are shown in figures 1(a) through 1(d).

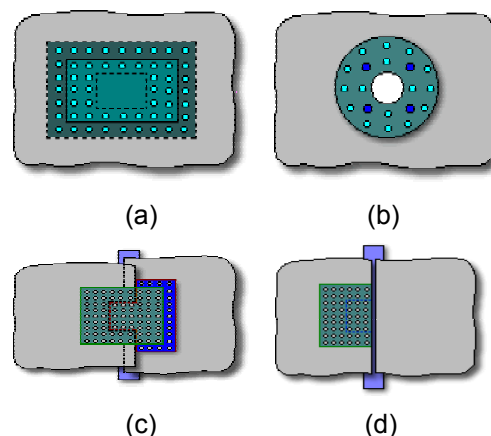


Figure 1. Typical Repair Configurations for Fuselage Skin Repairs

The built-in doubler configurations for antenna installations are shown in figures 2(a) through 2(e). Only the circular cutout is allowed.

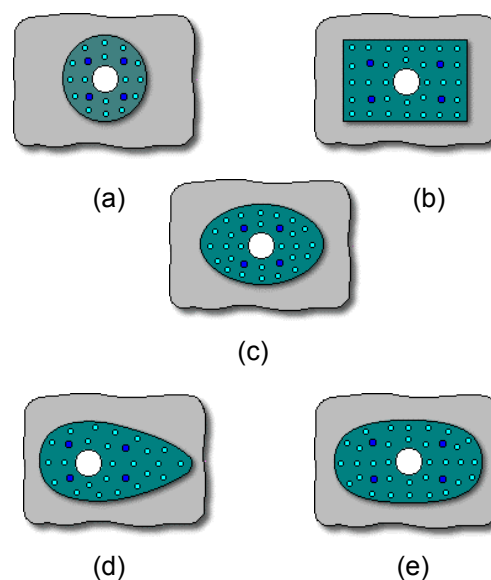


Figure 2. Typical Repair Configurations for Antenna Installations

A new capability for irregular fastener pattern was also implemented into the RAPIDC design process. This capability allows users to place fasteners as they were found in an operational environment, as illustrated in figures 3(a) and 3(b), rather

than the straight line previously required by the program. This feature is especially critical for the designs of the elliptical, sausage, and teardrop doublers.

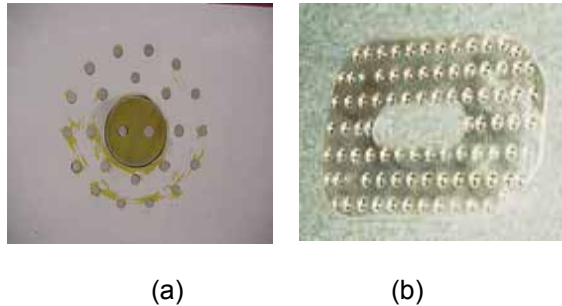


Figure 3. Typical Field Repair Configurations With Irregular Fastener Patterns

A detailed repair assessment report is automatically generated. The report includes all the design parameters and configurations, analysis methodologies, and results from damage tolerance analysis.

Typical results such as fatigue crack growth history, residual strength, and critical crack length are plotted in figures 4(a) and 4(b).

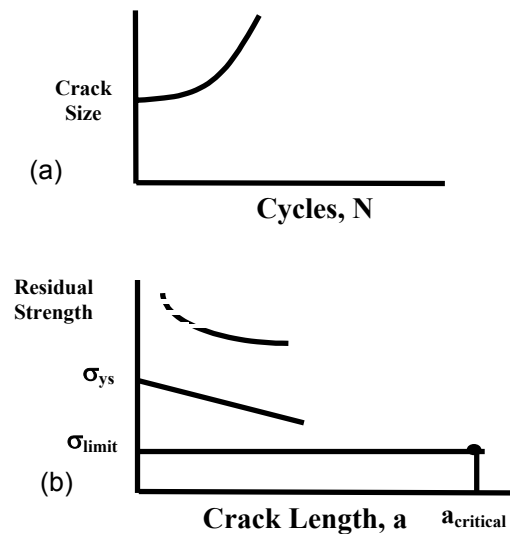


Figure 4. Typical Results From Damage Tolerance Analysis

Michael Shiao, AAR-480, (609) 485-6638

## Data and Methodologies for Structural Life Evaluation of Small Airplanes

Under FAA funding, the Wichita State University National Institute for Aviation Research, in collaboration with small airplane manufacturers, is developing a structural-life evaluation methodology for small airplanes. The purpose of this task is to support the revision of Advisory Circular (AC) 23-13, "Fatigue and Fail-Safe Evaluation of Flight Structure and Pressurized Cabin for Part 23 Airplanes." AC 23-13 currently references Flight Standards Services (AFS)-120-73-2, "Fatigue Evaluation of Wing and Associated Structure on Small Airplanes," which will be superseded by the revised AC 23-13. The original AFS-120-73-2, published in 1973, is based on incomplete usage and

material data. The data and results from this research will be included in the revised AC 23-13 for the continued evaluation of structural health for the aging small airplane fleet.

An initial review of published loads spectra and usage data has been conducted by Wichita State University. Typical loads exceedance spectra are shown in figure 1. The solid lines are the weighted mean, and the symbols are individual airplanes. As indicated, the scatter with respect to the group mean is large. Scatter can be better understood by examining airplane operational usage statistics such as altitude, airspeed, and flight duration. Flight duration data for typical single-engine airplanes are shown in figure 2. Loads spectra can be further analyzed in terms of the statistical moments for load factors and operational

usage. The resulting spectra can then be completely specified in terms of the statistical moments and the type of distribution.

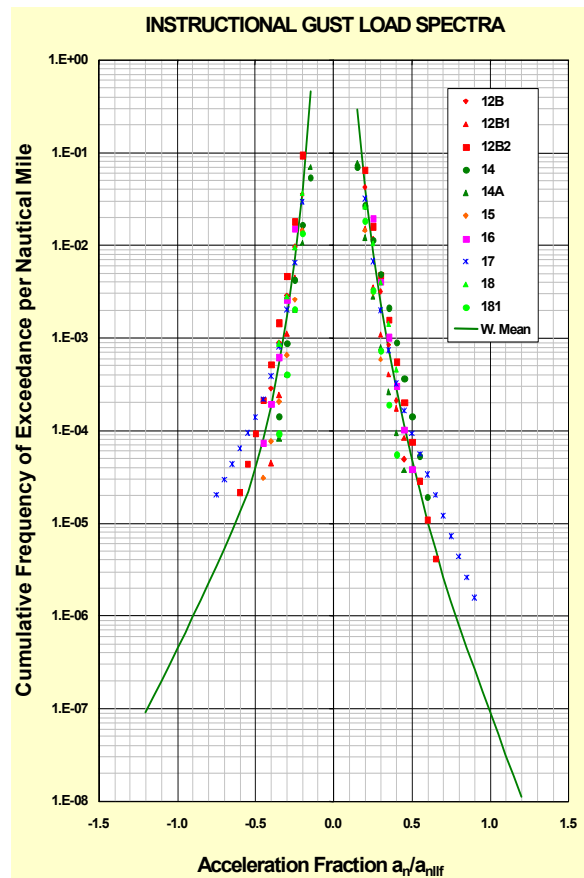


Figure 1. Instructional Single-Engine Airplane Gust Exceedance Spectra

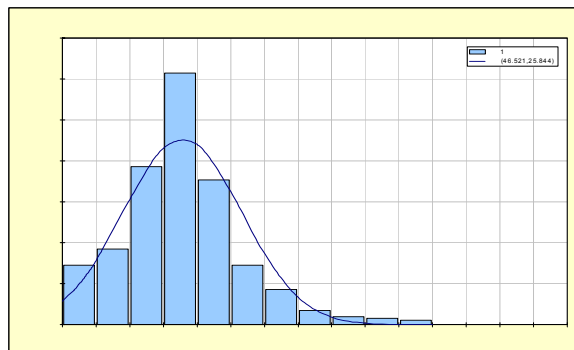


Figure 2. Single-Engine Flight Duration

Analytical loads spectra that are based on statistical moments have three distinct advantages compared to a completely empirical spectra: (1) load levels that are not contained in the original data can be determined; (2) an analytical relationship between the airplane's acceleration at its center of gravity and load conditions, such as gust load, maneuver load, and landing load, can be developed; and (3) uncertainties in the loads estimates can be evaluated.

The current AFS-120-73-2 fatigue life evaluation methodology uses S-N curves that were based on full-scale test results of surplus military airplanes. The FAA Fatigue Working Group noted that this approach often produces unrealistic estimates for fatigue life. Furthermore, the S-N data are based on one type of wing structure with no means of directly accounting for stress concentrations and load transfer. Two existing methods, Stress Severity Factor and S-N Fatigue Severity Index, were used as a basis for developing a fatigue life methodology that accounts for structural details, full-scale structural complexities, and loading spectrum. The end result will be a method that uses conventional stress concentration factors (that are functions of the structural detail) and empirical factors to determine the effective stress concentration factor for the structural detail. With a known effective stress concentration factor, fatigue life can be determined from conventional S-N data. Further modifications are required to correct for full-scale structural effects and loading spectrum effects. These modifications are also represented in terms of empirical factors.

Experimental work to generate appropriate empirical factors has begun. A typical test arrangement is shown in figure 3.

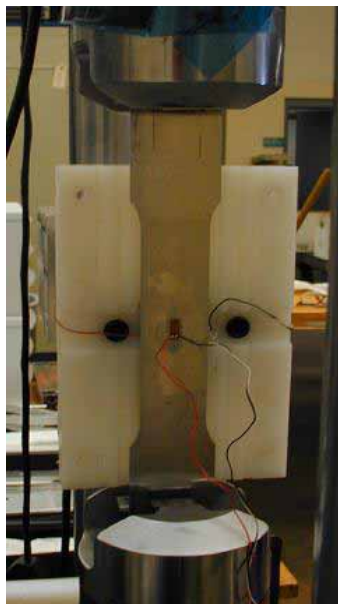


Figure 3. Test Specimen With Strain Gages and Antibuckling Fixture

For clarity, half of the antibuckling fixture has been removed. The shown specimen is loaded at a representative 1-g mean stress level with an appropriate alternating stress level. Antibuckling fixtures are required because many of the specimens must be tested at negative R-values to produce failure in the desired range of cycles.

Final project deliverables are (1) an unlimited distribution document and database that contains credible S-N curves and statistical exceedance spectra, (2) technical data to develop guidance material to support rulemaking, and (3) a structural-life evaluation methodology for small airplanes.

Michael Shiao, AAR-480, (609) 485-6638

## Bonded Repair of Composite Sandwich Structures

With the increasing use of fiber-reinforced composite sandwich structures in aircraft components, it has become necessary to develop repair methods that will restore the component's original design strength without compromising its structural integrity. One of the main concerns is whether large repairs are always necessary to restore strength or whether smaller, less-intrusive repairs can be implemented instead. Cure temperature can also become an issue if the repair patch requires curing at 350°F. Residual thermal stresses due to the bonding of the patch to the parent structure may induce further damage to the component. With these concerns in mind, the main objective of this study was to evaluate the effectiveness of scarf repairs applied to sandwich structures, given several bonding repair variables.

The first task investigated the performance of different airline depots in repairing picture frame shear elements using two different repair methods: the Society of Automotive Engineers (SAE) Commercial Aircraft Composite Repair Committee (CACRC) developed a wet lay-up procedure and an OEM prepreg procedure. Each method had different cure temperatures and used different materials. Furthermore, the wet lay-up method required an extra ply, while the OEM method did not. Another difference between the two methods involved the scarf overlap: the wet lay-up method used the conventional 0.5-inch scarf overlap, while the OEM method used a steeper 0.25-inch scarf overlap. All the repaired coupons achieved at least 92% of the average pristine strength regardless of the repair method, as illustrated in figure 1, except those coupons from one airline depot that seemed to have been poorly bonded.

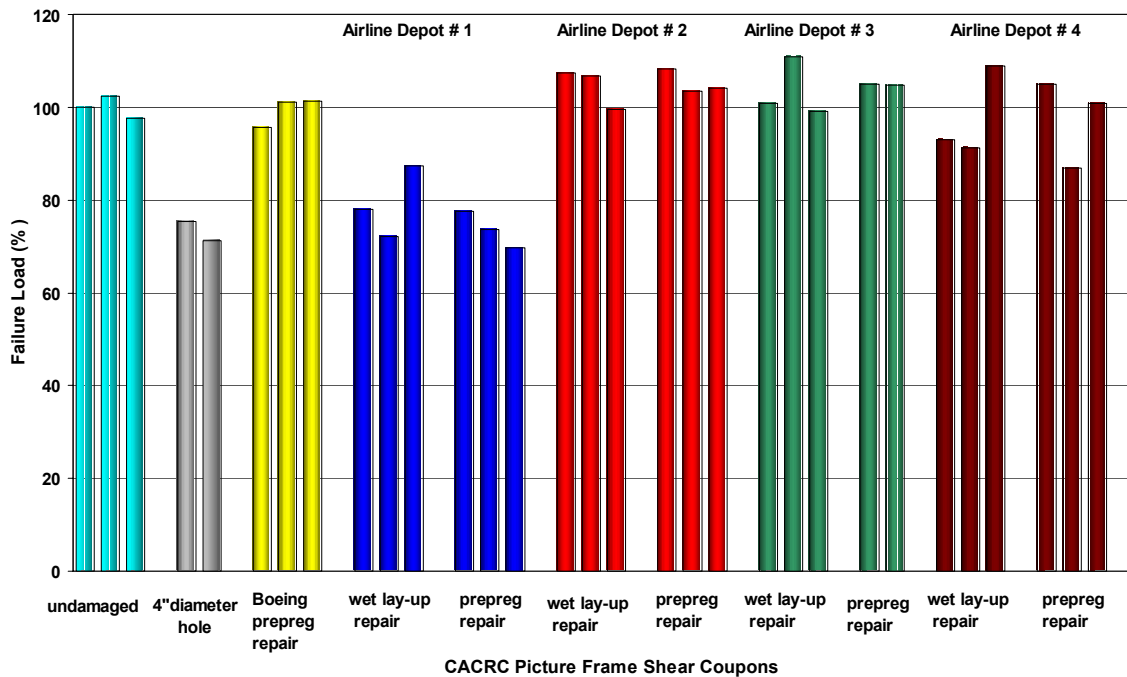


Figure 1. Performance of Field Station Repairs Versus OEM Repairs

The second task performed in this investigation examined the effect of different repair variables on repair performance. The variables considered included three different scarf overlaps, two different core cell sizes (1/8 and 3/8 inch), and impact damage inflicted on the repair. Test results on large four-point bending beams with 1/8- and 3/8-inch cells are shown in figures 2 and 3. There was no change in strength or failure strain as a function of increasing scarf overlap for the 1/8-inch cells (figure 2); however, when barely visible impact damage was inflicted on the overlap area of these coupons, a decrease in failure strain of up to 20% was found for the small overlap length coupons, figure 3. The behavior of the 3/8-inch cells was quite different as the failure strain decreased for the 0.5-inch overlap length for the undamaged large four-point bending beams, figure 2.

The damaged 3/8-inch cell coupons exhibited the same trend with respect to

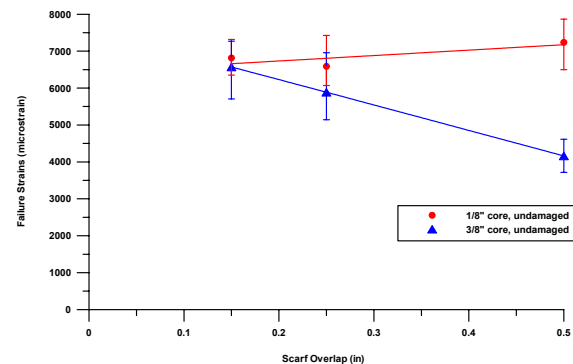


Figure 2. Effect of Core Cell Size on the Failure Strains of Undamaged Large Beams

scarf ratio, i.e., overlap length (figure 3). Furthermore, damage inflicted in the scarf area caused a decrease in the strength and strain capacities on the order of 10% and 23%, respectively, relative to the undamaged coupons. From the test results, it is apparent that the optimum overlap length is 0.25 inch irrespective of core cell size. It was also found that the 1/8-inch core beams had higher failure strains than the

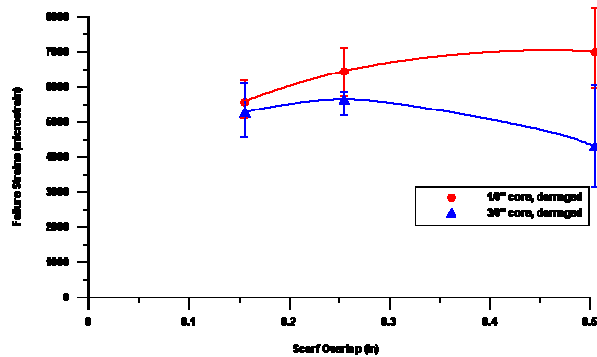


Figure 3. Effect of Core Cell Size on the Failure Strains of Damaged Large Beams

3/8-inch core coupons for both undamaged and damaged states.

The research performed validates the use of the CACRC repair procedures that are documented in numerous SAE publications and establishes the optimum scarf length for repair of facesheets of composite sandwich structures.

Peter Shyprykevich, AAR-450, (609) 485-4967

## Quality Assurance Methods for Fiber-Reinforced Composites

General aviation has primarily dominated the recent growth of new composite aircraft and composite material applications in primary structures. Figure 1 shows three types of composite structure aircraft that are

currently being certified. With this growth of general aviation composite applications, certification issues have emerged with respect to the exact philosophy of quality control and assurance methods required to guarantee a safe and consistent material supply.



Figure 1. Composite General Aviation 14 CFR Part 23 Aircraft That are Currently Being Certified

Unlike metallic materials used in structural part manufacturing processes, the material properties of composite materials are dependent on the fabrication process. Therefore, it is essential that material procurement and processing specifications used to produce composite structures contain sufficient information to ensure that

critical parameters in the material manufacture and structural fabrication process are controlled and they maintain adherence to the expected part requirements. Due to the wide variety of composite structures now emerging for certification (particularly for general aviation aircraft),

control of the materials is rapidly becoming a vital issue with respect to the overall assurance of safety.

In composites, a key link in the overall part and application success is the material and process specifications used for the design. Currently, most general aviation manufacturers generate material and process specifications that are unique to them, and each manufacturer places those unique requirements upon the material vendor. These multiple material and process specifications then cause the vendor to tailor the same material supplied to different companies in order to meet the companies' individual specification. This leads to an unstable material supply that requires additional control at the airframe manufacturer to guarantee adherence to the specification and design application. Metallic materials do not suffer the same complication in manufacture and delivery because of availability of common industry specifications.

The performed research identified all criteria for both material procurement specifications and material fabrication specifications based on known quality assurance methodology. It also identified areas requiring quality assurance development. In the areas needing additional technology or research for manufacturing and fabrication process controls, this project proposed new investigations to develop a methodology to meet the goal of consistent and reliable control of composite products.

For material procurement control criteria, the following items were considered: basic fiber, matrix, and cured component characteristics; chemical, mechanical, and physical properties; safety and health information; transportation; storage; handling; and testing, including type,

number, and frequency of tests. For processing control criteria, the following were considered: process information, including fabrication methods and environmental conditions; inspection criteria at each operation; storage and handling throughout the process; process controls (cure cycle parameters, out time); materials; test specimen construction and processing; personnel qualifications; and tool proofing and control.

The developed guidelines for material procurement and processing specification requirements included the best industry practice in testing, data analysis, inspection, material and process control as enumerated in the surveyed specifications, investigators experience, and industry review.

The following FAA technical reports were produced giving guidelines in material procurement and processing specification requirements for unidirectional prepreg tape material systems.

- “Guidelines for the Development of Process Specifications, Instructions and Controls for the Fabrication of Fiber-Reinforced Polymer Composites,” DOT/FAA/AR-02/110, Bogucki, G., et al., March 2003.
- “Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs,” DOT/FAA/AR-02/109, McCarvill, W., et al., March 2003.

The Material Specification Guidelines report (DOT/FAA/AR-02/109) recommends guidance and criteria for the development of material specifications for carbon fiber-epoxy unidirectional prepreg tape materials used on aircraft structures. A team of

industry experts in material specifications, part processing, qualification programs, and design allowables prepared these recommendations. The purpose of this report was to establish recommendations to guide the development of new and revised composite prepreg material specifications. A generalized approach to the development of a shared composite material database was proposed. The approach in this document will remove the restrictions placed on the methods developed by the Advanced General Aviation Transport Experiments to allow a broader market to use the shared database.

The Processing Specification Guidelines report (DOT/FAA/AR-02/110) provides (1) a set of guidelines for the development of process information for the fabrication of continuous fiber-reinforced polymer composite laminate test panels used in the generation of mechanical properties and (2) an approach for the validation of composite fabrication processes used during the certification of composite aircraft structure. A team of industry experts in generating material specifications, processing of composite materials, qualification program management, and design allowables development prepared these guidelines. The guidelines use state-of-the-art processes and sound engineering practices currently used within the aerospace industry.

The success of the initial project led to a second phase to produce similar documents for a fabric carbon fiber system and a liquid resin molding (LRM) system (e.g., resin transfer molding, vacuum-assisted resin transfer molding, and resin film infusion). Phase II will add guideline information for fabric reinforcement and guidance and recommendations for advanced LRM systems. LRM processes are unique in that the raw materials are, many times, from multiple sources. No single producer is able to certify that the combined constituents conform to expected standards. In addition, the combining of the materials in the part fabrication creates more unknowns in the repeatability of the engineering properties and adds complexity in the validation and FAA certification process.

This work provides the first level baseline for the establishment of material procurement and processing control, which will meet FAA requirements. The ultimate goal is to provide a catalyst to the initiation of industry standardization that the metallic materials community has enjoyed for years. These documents form the basis for a new FAA Advisory Circular that will be released in FY04. With the initiation of Phase II, a larger range of applications will develop standardized control methodology.

Curtis Davies, AAR-450, (609) 485-8758

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## **Metallic Materials Properties Development and Standardization**

The 3<sup>rd</sup> Metallic Materials Properties Development and Standardization (MMPDS) Coordination Meeting was held April 14-17, 2003, in Las Vegas, NV. The meeting was well attended with over 50 participants and was held in concert with the first release of the MMPDS-01 Handbook,

the replacement document for MIL-HDBK-5. The Handbook is recognized internationally as a reliable source of aircraft materials data for aerospace materials selection and analysis. Consistent and reliable methods are used to collect, analyze, and present statistically based material and fastener-allowable properties. The Handbook is the only publicly available source in the U.S. for material allowables

that the FAA generally accepts as being compliant with the FAR for material strength properties and design values for aircraft certification and continued airworthiness. Moreover, it is the only publicly available source worldwide for fastener joint allowables that comply with the FARs.

This year marks the first year of publication of the MMPDS Handbook and the final year of publication of MIL-HDBK-5. For this year only, MMPDS-01 and MIL-HDBK-5J will be technically equivalent. In the spring of 2004, when the 1<sup>st</sup> Change Notice of MMPDS-01 is published, MIL-HDBK-5 will be designated noncurrent, and MMPDS will become the only government-recognized source in the U.S. of published

design-allowable properties for metallic commercial and military aircraft structures and mechanically fastened joints. This maintains the 65-year legacy of MIL-HDBK-5 and its predecessor the Army-Navy-Commerce Handbook 5.

The MMPDS Handbook can be obtained from the National Technical Information Service, NTIS, at <http://www.ntis.gov/> for a nominal fee. The MMPDS Handbook is available in two formats: (1) microfiche for \$116.50 plus shipping and (2) paper copy for \$223.50 plus shipping. The MMPDS Handbook can also be downloaded in PDF format free of charge at the FAA William J. Hughes Technical Center library's website <http://actlibrary.tc.faa.gov/>.

John Bakuckas, AAR-480, (609) 485-4784

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## **Characterization of Fatigue Behavior of Aircraft Fuselage Structures**

A major focus of the structural integrity research supporting the FAA National Aging Aircraft Research Program has been the assessment of fatigue mechanisms in aircraft structure through computational and experimental analysis. Emphasis has been placed on determining the causes, growth mechanisms, and consequences of widespread fatigue damage (WFD). Knowledge of multiple-site damage (MSD) nucleation time, pattern, and distribution, as well as its subsequent growth and effects on residual strength, is a prerequisite for planning an acceptable program to preclude the occurrence of WFD.

As part of the FAA's core capability, a unique, state-of-the-art Full-Scale Aircraft Structural Test Evaluation and Research facility has been established at the FAA William J. Hughes Technical Center for

testing large curved panels representative of aircraft fuselage structure. This facility provides experimental data to support and validate analytical methods under development, including WFD prediction, repair analysis and design, and new aircraft design methodologies. The fixture, shown in figure 1, is designed to simulate the actual loads an aircraft fuselage structure is subjected to while in flight, including differential pressure, longitudinal load, hoop load in the skin and frames, and shear load.

Several programs have been undertaken to investigate the fatigue and residual strength characteristics of fuselage structure. A variety of fuselage panels were tested and analyzed, including undamaged panels and panels manufactured with crack-like slits to simulate initial damage scenarios. In addition, a panel with polyisocyanurate foam was tested to assess its effect on fatigue behavior. For each panel tested, strain surveys were first conducted to ensure proper load transfer from the load

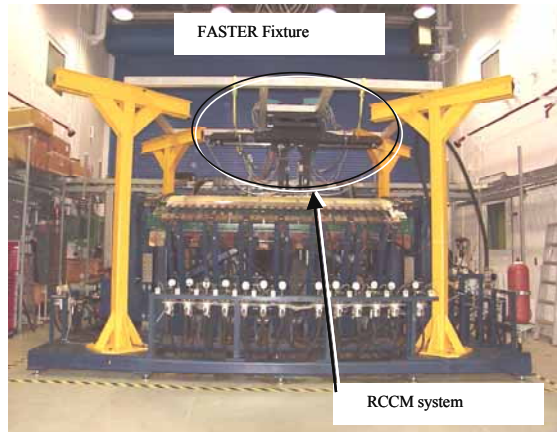


Figure 1. Full-Scale Aircraft Structural Test Evaluation and Research Facility

application points to the panels. Fatigue damage was quantified in terms of crack initiation, crack distribution (location and size), and subsequent growth. Residual strength tests were conducted to determine the effects of damage states on load-carrying capacity.

Test results during the strain survey revealed a high local-bending deformation along the critical outer rivet row in the lap joint area, the same area where MSD cracks initiated. As shown in figure 2, there is more local bending for a curved panel CVPB compared to the flat panel test results. The flat panels tested had identical joint construction to the curved panel CVPB. For both panels, the maximum strain occurred at the inner skin surface.

The majority of fatigue life was spent in initiating and forming cracks. Cracks initiated from the inner-faying surface at rivet holes in the outermost fastener row in the lap joints and progressed through the thickness, as illustrated in figure 3. Once first linkup occurred, crack growth rate increased substantially.

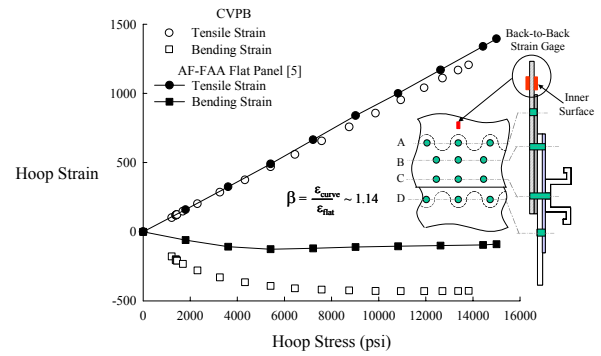


Figure 2. Strain Near the Lap Joint in a Curved Panel CVPB and a Flat Panel

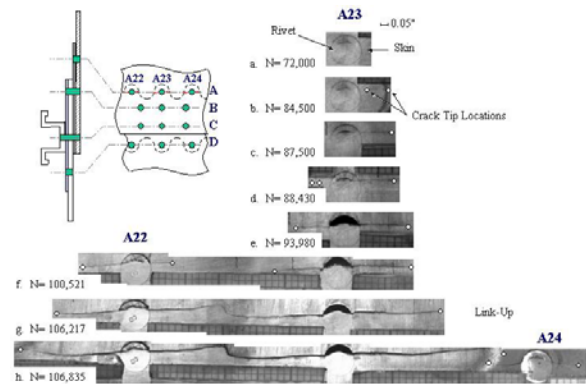


Figure 3. Crack Growth Process in the Outer Critical Rivet Row

Although multiple cracking did not have an effect on the overall global strain response, it significantly reduced the fatigue life and residual strength, as shown in figure 4.

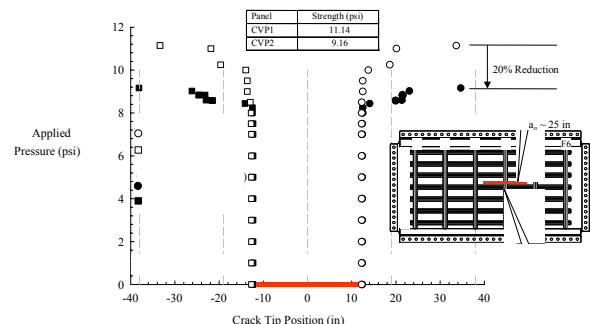


Figure 4. Residual Strength Data for Panels CVP1 and CVP2

In addition, the application of polyisocyanurate foam to fuselage panels was effective, enhancing crack growth performance. More details can be found in Bakuckas, J.G., Bigelow C.A., and Tan, P., "Characterization of Fatigue Behavior of

Aircraft Fuselage Structures," *Proceedings From the International Committee on Aeronautical Fatigue* (ICAF 2003), Lucerne Switzerland, May 2003.

John Bakuckas, AAR-450, (609) 485-4784

## Crack Growth of Rotorcraft Materials

One milestone of the FAA National Aging Aircraft Program Plan is to review and update 14 CFR Part 29 regulations and AC material regarding aging issues. The goal is to include damage tolerance (DT) requirements in 14 CFR Part 29.

In 2000, the FAA started the rulemaking process and initiated several joint rotorcraft research and development efforts to support the implementation of the DT requirements and the development or revision of applicable ACs. The FAA plans to implement the DT rule in the future.

One of the research efforts funded by the FAA and conducted by the University of California, Irvine was to examine and quantify the impacts of current life enhancement methods on fatigue life in rotorcraft by focusing on the development and validation of a generalized crack growth analysis model appropriate for all possible rotorcraft components and operating conditions.

To improve the fatigue life of metallic components, especially in the rotorcraft industry, shot peening is widely used. Shot peening is a cold-working process primarily used to extend the fatigue life of metallic structural components. Small spherical particles, typically made of metal with a high hardness, are made to impact the surface of the structural component at a velocity of 40-70 m/s. The shot-peening

process consists of multiple repeated impacts of a structural component by these hard spheres causing local plastic deformation, as shown in figure 1. The elastic subsurface layers should theoretically recover to their original shape during unloading. However, continuity conditions between the elastic and plastic zones do not allow for this to occur. Consequently, a compressive residual stress field is developed in the near-surface layer of the structural component. Since fatigue cracks generally propagate from the surface of structural components, the resulting surface compressive residual stress field is highly effective in improving the early fatigue behavior of metals. The compressive residual stress field can significantly decrease the crack growth rate of short surface cracks. As a result, the extension of fatigue life of shot-peened structural components can be determined.

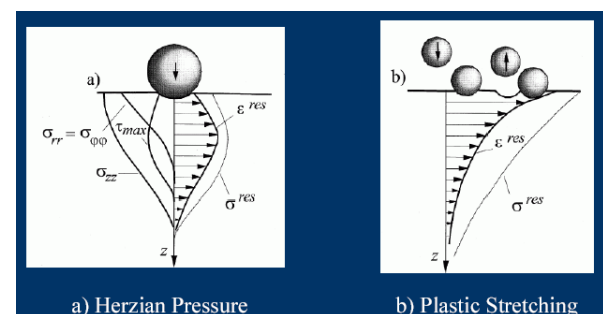


Figure 1. Mechanical Effects Due to Shot Peening

Despite the complexity of the shot-peening process, there have been attempts to determine the residual stress field using

approximate approaches and closed-form solutions. However, application of the Hertzian contact theory and an approximate elastic-plastic analysis for the surface layer can better estimate the distribution of the compressive residual stress field due to shot peening, as shown in figure 2. Residual stress distributions with better precision can be obtained with the use of numerical methods and computer simulation of the whole shot-peening process. Typically, the shot-peening simulation is divided into two steps. The first step is a dynamic analysis of the shot workpiece contact, which is aimed at the determination of boundary conditions for the second elastic-plastic step. The second step is a quasi-static elastic-plastic analysis, which produces the distribution of residual stresses.

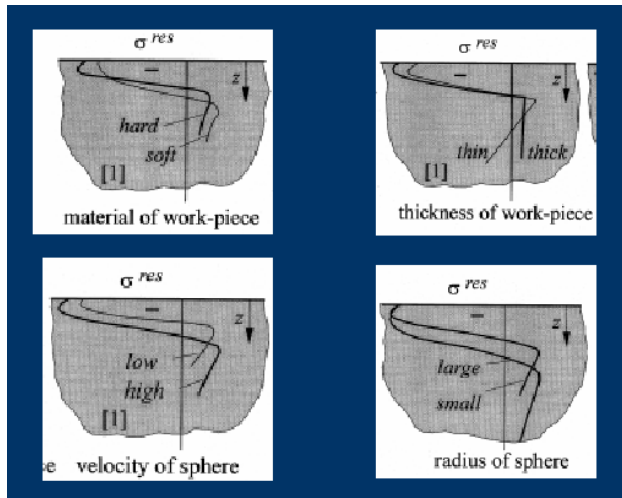


Figure 2. Influence of Shot-Peening Parameters on the Distribution of the Residual Stresses

Early models used to predict residual stresses describe the shot-peening process as a quasi-static case. As a result, the velocity of the shot is not taken into account, and empirical parameters are used. The newly enhanced model developed under this current research takes the primary shot-peening factors into consideration, including

characteristics of the material, diameter, and velocity of the shot.

The flow chart in figure 3 depicts the enhanced model for the calculation and prediction of the residual stresses due to shot peening. In this enhanced model, no empirical relations or parameters are used.

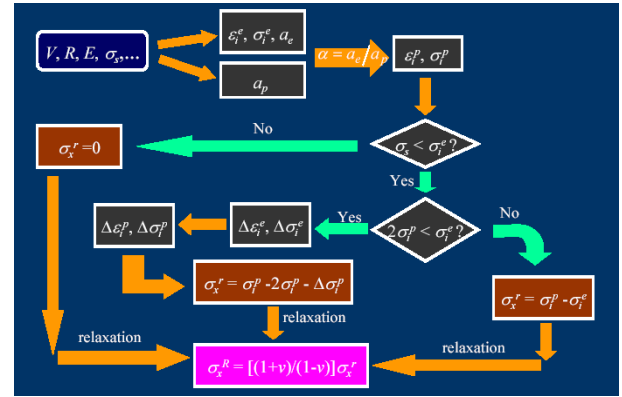


Figure 3. Flow Chart of the Enhanced Model Used to Calculate Shot-Peening-Induced Residual Stresses

The approach used in this research to model fatigue crack growth in shot-peened structural components, as shown in figure 4, consists of (1) using the finite element alternating method for computing fracture mechanics parameters for the crack and (2) using the approximation approach based on the plastic strip model for predicting crack growth rates.

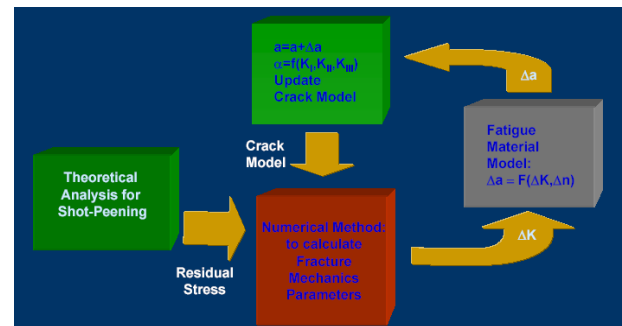


Figure 4. Modeling Fatigue Crack Growth in Shot-Peened Structural Components

The crack is modeled by the Symmetric Galerkin Boundary Element Method as if it were in an infinite medium. The finite element method is independently used for the stress analysis of the uncracked structural component subjected to the applied loading. Proper superposition of two solutions was applied through the use of an iterative-alternating procedure. The effect of the residual compressive stress field on crack propagation was performed via an analysis of shot-peened 7075-T7351 aluminum plates (1.8-mm-thick, double-edged specimens). Figure 5 shows the fatigue crack growth ( $da/dN$ ) data versus the stress-intensity factor range ( $\Delta K$ ) of 7075-T7351 specimens. AGILE 3D and NASGRO models were used to simulate the tests and demonstrate the effect of the shot peening on fatigue crack growth.

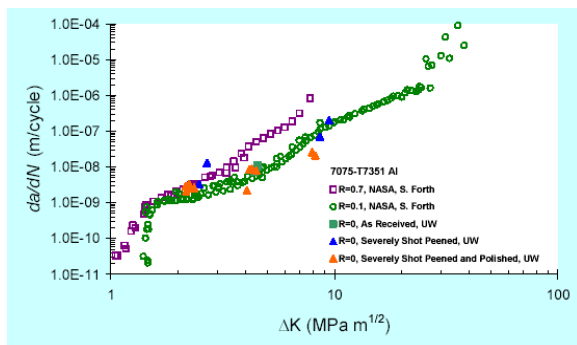


Figure 5.  $da/dN$  vs.  $\Delta K$  of a Double-Edged Sharp Notch Specimen

The plot in figure 6 depicts the effects of shot peening on fatigue crack growth. Full validation of the developed model for the calculation and prediction of the residual stresses due to shot peening and other life enhancement techniques is needed for use in advisory materials. Design optimization techniques, through which the fatigue lives of rotorcraft components can also be optimized, will also become available for use in advisory materials.

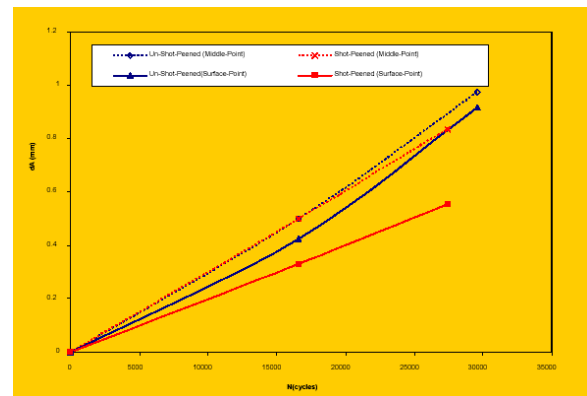


Figure 6. Effects of Shot Peening on Fatigue Crack Growth

Dy Le, AAR-480, (609) 485-4636

# Mechanical and Electrical Systems Reliability and Integrity



## Material Testing Research and Indenter Development for Determining Aging of Wires in Aircraft

In support of the Enhanced Airworthiness Program for Aircraft Systems, the FAA is committed to the research and development of advanced technologies for nondestructive inspection and nondestructive testing of aircraft electrical wiring interconnect systems (EWIS). The objective of this research project was to determine if changes in the hardness of wire insulation system correlate with other accepted, though destructive, test methods. Development of a portable, simple-to-use instrument for performing these measurements was conducted in parallel with the research effort.

Analog Interfaces, Inc., originally developed this approach in the 1980s for assessing wire installed in commercial nuclear power plants. The Electric Power Research Institute sponsored the research. A suitably sized indenter tool was developed for obtaining the measurements. The indenter was demonstrated to be a nondestructive test method for monitoring the aging of wires and cables by measuring the changes in compressive modulus, a mechanical property of insulation material.

Aging wires cause embrittlement and cracking that may result in significant electrical malfunctions and dangerous conditions such as electrical arcing. Changes in mechanical properties typically have been evaluated by elongation-at-break (EAB) testing. However, EAB testing is destructive and requires relatively large specimens, making it undesirable for analyzing installed cables. The indenter is a portable, simple-to-operate nondestructive instrument used for gathering data that can

be correlated with EAB data, providing a relative measure of wire degradation. As an alternative to EAB tests, indenter tests provide a systematic indication of material aging. Periodic indenter measurements of an installed aircraft wire can be compared to EAB-indenter correlation graphs to monitor the progression of cable degradation.

Specific activities completed were as follows:

- Redesign and modification of the Analog Interfaces, Inc.'s indenter for compatibility with small-gauge aircraft wires and for portability of the system for use within confined aircraft spaces.
- Development of standardized test processes for using the modified indenter.
- Accelerated thermal aging of various aircraft wire types currently used in aircraft.
- Evaluation of the effects of accelerated aging on the insulation systems by performing indenter modulus, EAB, and wire insulation deterioration analysis system tests and evaluation of correlations between the methods.

The research included six general-purpose wire types commonly used in aircraft EWIS, including polyvinyl chloride (PVC), PVC/glass/nylon, XL-ETFE (cross-linked Tefzel), composite TKT (Teflon<sup>®</sup>-Kapton<sup>®</sup>-Teflon<sup>®</sup>), polyimide (Kapton<sup>®</sup>), and polyimide (Kapton<sup>®</sup>) #10 American Wire Gage power cable.

An indenter measurement (see figure 1) is simply obtained by the following process. The operator prepares for the test by pulling back on a trigger on the Cable Clamping

Assembly to open a jaw clamp, inserting the wire in the clamp, and releasing the trigger, which holds the wire firmly in place (see figures 2 and 3). The operator presses the SCAN button on the indenter, and the probe starts moving toward the wire. When it contacts the wire, data measurements of force and displacement (probe movement) are obtained at 100 samples per second. When the force sensor records a reading of 2 pounds, it stops further advancement of the probe, avoiding damage to the insulation.

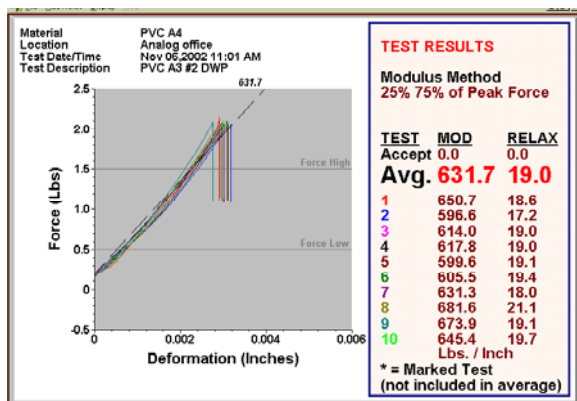


Figure 1. Typical Modulus Measurement Display



Figure 2. Cable Clamp Assembly, Top View

During a standard modulus test, the probe immediately retracts when the force reads 2 pounds. In this project, research was also



Figure 3. Clamp Assembly, Close-Up View

conducted on a second variable called the relaxation value. The relaxation value is determined by measuring the decay in the force at the probe tip for a period of time after the probe tip initially reaches 2 pounds. Obtaining relaxation data takes about 7 seconds and then the probe retracts. Modulus and relaxation values are displayed, and the system is automatically set to take the next data point.

Based on the results, the following conclusions can be stated:

- The accuracy of the data obtained by the indenter is operator independent. Previous indenter experience is not necessary for obtaining accurate measurements.
- The new indenter is suitable for testing small wires installed in aircraft and produces reliable data.
- The indenter results correlate well with other test methods, though further thermal aging is required to more fully establish the relationship.

Results of this project indicate that the indenter is a viable nondestructive method for monitoring the progression of wire degradation in aircraft. Additional research is planned to develop correlation data on additional wire types and to research the

relationship between indenter measurements and the probability of dielectric failure.

Robert A. Pappas, AAR-480, (609) 485-6181

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## Use of COTS Real-Time Operating Systems

Using commercial off-the-shelf (COTS) software and hardware in airborne systems has the potential to (1) offer significant cost savings for small aircraft and rotorcraft, (2) reduce project development time and the associated cost, and (3) increase aircraft safety if lower-cost systems could be shown to be safe and would allow the replacement of older, less capable systems. However, there is substantial concern in the aerospace industry whether methods are available or could be found for evaluating COTS used in airborne systems. Moving maps, graphical weather, situational awareness, and cockpit display of traffic information could be used in general aviation applications if efficient methods of assessing COTS were available. To address these concerns, United Technologies Research Center, under FAA funding, produced technical information for use in the development of regulatory guidance on COTS software and hardware used in flight controls and avionics systems.

COTS Real-Time Operating System (RTOS) provides a variety of services to application software within a system. As RTOS services and capabilities grow in complexity, it is clear that they have an increased influence on the overall system performance and, as such, should have consideration in an overall system safety assessment.

The current research completes the fourth phase of a study regarding COTS

components. The first and second phases considered issues on the use of both software and hardware electronic COTS components in aviation systems and produced two reports:

- “Commercial Off-The-Shelf (COTS) Avionics Software Study,” DOT/FAA/AR-01/26, Krodel, J., May 2001.
- “Review of Pending Guidance and Industry Findings on COTS Electronics in Airborne Systems,” DOT/FAA/AR-01/41, Thornton, R., August 2001.

The third phase took a detailed look into the safety and certification issues of using a COTS RTOS in aviation applications and produced the report titled “Study of Commercial Off-The-Shelf (COTS) Real-Time Operating Systems (RTOSs) in Aviation Applications,” DOT/FAA/AR-02/118, Halwan, V., et al., December 2002. The fourth and final phase of COTS research builds upon the previous phases.

The fourth phase investigated the safety aspects of using a partitioned COTS RTOS and its integrated architectural features in aviation systems. Because of the complexity and unknown integrity of many COTS RTOS, there are a number of concerns regarding their use in aircraft systems as they may potentially affect aircraft safety. The fourth phase provides an in-depth study into the considerations of using partition-supporting COTS RTOS in aviation systems.

The research specifically studied the hardware and software architectural issues of embedded aviation software systems, with a particular focus on systems with multilevel criticality partitioning provided by the COTS RTOS. The microprocessor features and associated RTOS services are many, and their implementation can vary from application to application and RTOS to RTOS. As a representative example, the research also addressed the PowerPC microprocessor architecture, and how its architecture relates to the safety aspects of the COTS RTOS running on this processor.

Partitioned systems are seen as a natural vehicle for protecting various levels of software, as defined in the Radio Technical Commission for Aeronautics document “Software Considerations in Airborne Systems and Equipment Certification,” DO-178B, and are candidates for supporting integrated modular avionics (IMA) systems. Aviation applications, in a desire to reduce computing resources in their systems, have established a need to move to IMA architectures. At the center of the integrated architecture is the RTOS, which provides services to the system and interacts with

highly complex microprocessors to achieve the goals of the system. These complex microprocessors contain features that are controlled by the RTOS and affect the overall safety of the system. The research shows that a partition-supporting RTOS is just a part of the overall system’s protection mechanism, and that further research is needed in the integration of RTOS, applications, and IMA systems in general. As an example of partitioning, figure 1 shows the logical memory layout of a partitioned system.

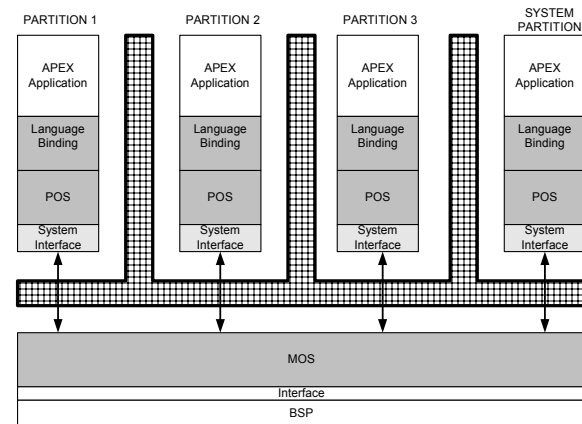


Figure 1. Multiple-Application Memory Layout

Charles Kilgore, AAR-470, (609) 485-6235

## Characterization of Test Bed Aircraft

In response to the initiation of the new Aging Mechanical Systems Program, the FAA purchased a B747-136 (figure 1) to serve as a program test bed for investigating aging mechanical systems. The aircraft was decommissioned in a manner to ensure the continued functionality of its mechanical and electrical systems. The test bed is available to support any future testing of mechanical systems.

In December 2002, the FAA technical note “Mechanical Systems Characterization of Boeing 747 Aging Systems Test Bed Aircraft,” DOT/FAA/AR-TN02/119, was published. The report indicates that most systems, required for ground testing, were found to operate and function, or were serviced to operate and function, in accordance with the basic system functionality requirements specified in the Boeing 747-100 Maintenance Manual. These systems include the following: pneumatic system, hydraulic system,

trailing-edge flap systems, leading-edge devices, aileron system, spoiler system, elevators, horizontal stabilizer, hydraulic shutoff valves, air conditioning, fuel system, landing gear system, lighting, doors and escape hatches, cargo handling, potable water, and lavatories.

Several systems were found to be nonoperational and would require a

substantial financial expenditure in replacement components to make them operational. It was decided to leave these systems alone at this time; they include cabin pressurization, autopilot, navigation, communication and radio equipment, entertainment systems, interphone and public address system, oxygen system, ice and rain system, and fire systems.



Figure 1. FAA Test Bed Aircraft

Robert McGuire, AAR-480, (609) 485-4494

# Propulsion and Fuel Systems



## Portable Industrial Process Monitor for Vacuum Arc Remelting

Vacuum arc remelting (VAR) is a process widely used throughout the specialty metals industry to produce finished cast ingots of superalloys and aerospace titanium alloys. In this process, the electrode tip is carefully heated in a controlled manner in vacuum, using a direct current electrical arc. The result is uniform electrode melting into a water-cooled copper mold. Successful VAR processing produces high-quality ingots that are free of oxide and nitride inclusions, as well as any of the several types of defects associated with uncontrolled solidification during casting. Because virtually all material used for forged rotating parts in gas turbine engines goes through a final VAR processing step, it is especially important that this process be carefully monitored to ensure production of defect-free material of uniform high quality.

The VAR Process Monitor is a process evaluation tool designed to aid in ensuring successful VAR processing. The monitor was developed jointly by the FAA, Sandia National Laboratories, and the Specialty Metals Process Consortium. It is compact, portable, and incorporates the latest advancements in process characterization, modeling, and data filtering. The heart of the system is a multistate process observer

developed as a result of more than 10 years of process research. Monitoring a VAR furnace with this system gives the remelting engineer real-time estimates of important process parameters impacting the successful production of defect-free castings, including some parameters that cannot be directly measured and are, therefore, unavailable by any other means. The monitor employs an intelligent measurements filter that can be used to eliminate questionable data points and flag the user when subtle process upsets occur (see figure 1). All monitor outputs are easily saved to data files that can be imported into common spreadsheet and plotting software. When used on a day-to-day basis, this technology can detect small changes in process conditions that normally go undetected and can, over time, degrade the quality of critical aerospace materials.



Figure 1. Portable Industrial Process Monitor

Joseph Wilson, AAR-460, (609) 485-5579

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## Unleaded Avgas Research Engine Testing

Effective January 1, 1996, one of the Clean Air Act Amendments banned the sale of leaded fuel for use in on-road vehicles, but exempted the sale of fuel containing lead for off-road uses, including aircraft, racing cars, farm equipment, and marine engines. As a result, the general aviation community is

now the largest consumer of leaded fuel in the United States. It is anticipated that economies of scale, and increasing environmental pressures, will eventually make the use of leaded fuels for general aviation prohibitive.

For more than a decade, the Propulsion Systems Branch (AAR-460) at the FAA William J. Hughes Technical Center has

worked closely with aircraft manufacturers, engine manufacturers, petroleum producers, and other regulatory agencies to facilitate the development of a safe alternative unleaded fuel. In this manner, the Technical Center has become the leading small piston aircraft engine test facility for unleaded fuels. The objective of this work is to develop robust test methods for unleaded aviation gasolines and to use these methods to validate the safe performance of prototype fuels.

Traditionally, engines and airframes have been certified on leaded fuels that meet the American Society for Testing and Materials (ASTM) standard specification D 910. Since the motor octane requirement for the majority of today's fleet flying on unleaded fuels is not known, a major aspect of the program has been to evaluate the performance of unleaded fuels in aircraft piston engines and to determine how performance varies from that of traditional leaded aviation gasolines.

To help address these issues, AAR-460 developed two new ASTM standard practices (ASTM D 6424-99 and ASTM D 6812-02), including combustion analysis methods devised by project personnel, for the determination of the actual engine motor octane requirement using unleaded reference fuels. Four of the highest octane requirement engines, two turbocharged and two naturally aspirated models, were octane rated at the FAA engine test facility under severe and repeatable conditions using unleaded reference fuels. A fuel that meets the octane requirements for these worst-case engines is expected to also meet the octane requirement of the majority of the piston engine fleet. With this knowledge in hand, petroleum producers could begin to formulate a new unleaded gasoline that satisfies the motor octane requirement of the

fleet and meets the majority of the ASTM D 910 fuel specifications. The data bank and expertise generated by the FAA small engine test facility with the testing of unleaded fuels has been instrumental in the recent and significant progress in the development of a candidate unleaded replacement fuel.

ExxonMobil Research and Engineering Company (EMRE) and BASF, a major chemical company, have worked closely with AAR-460 in an effort to prove the feasibility of prototype unleaded replacement fuels. In May 2003, AAR-460, under a Cooperative Research and Development Agreement with EMRE, performed a full-scale engine test on three candidate fuels supplied by EMRE and BASF. A Continental IO 550D, 6 cylinder, naturally aspirated 300-horsepower engine was tested at the FAA for 150 hours under severe and controlled conditions, which addressed issues of wear, performance, materials compatibility, deposit formation, startability, hot-fuel operation, and a host of other issues. The majority of the testing was performed at full-rated power and engine speed under maximum engine and oil temperatures. AAR-460 also knock-tested one prototype fuel in a Lycoming IO 540K, 6 cylinder, naturally aspirated 300-horsepower engine for comparison to the knock behavior of a 100 low-lead fuel in the same engine (see figure 1).



Figure 1. General Aviation Piston Engine

Although the final report has not yet been completed, the results of these full-scale engine tests on the prototype fuels appear to be very promising. The results have encouraged EMRE to consider the next steps that would be needed to validate the

performance of the prototype unleaded gasoline through engine certification and flight testing with a fleet of general aviation aircraft.

Stewart Byrnes, AAR-460, (609) 485-4499

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## **DARWIN<sup>®</sup>—A New Methodology for Surface Damage Tolerance Assessment**

A new probabilistic methodology has been developed for predicting the risk of fracture associated with aircraft jet engine rotors and disks subjected to surface damage. The methodology, defined by the Rotor Integrity Subcommittee of the Aerospace Industries Association, was recently implemented in Design Assessment of Reliability With Inspection (DARWIN<sup>®</sup>), a probabilistic fracture mechanics software code developed by Southwest Research Institute under FAA research and development (R&D) Grants.

DARWIN is being developed in collaboration with major engine manufacturers (General Electric, Honeywell, Pratt & Whitney, and Rolls-Royce). The 2000 R&D 100 award-winning program computes the probability of fracture as a function of the number of flight cycles, considering random defect occurrence and location, random inspection schedules, and several other random variables. A user-friendly GUI is included to handle the otherwise difficult task of setting up the problem for analysis and viewing the results.

Aircraft turbine rotors may be subjected to rare, critical events (e.g., uncontained engine failures) due to the presence of metallurgical (e.g., hard alpha) and manufacturing (e.g., surface damage) defects that can occur during the manufacturing process. A probabilistic methodology is particularly

well suited to the efficient design of components subjected to rare, critical (i.e., life-limiting) events, because it allows the designer to adjust nominal component parameters to meet quantitative reliability requirements.

Previous releases of DARWIN have focused on the risk assessment of titanium aircraft engine rotor disks with potential inherent (hard alpha) defects. Inherent defects can occur anywhere within a disk, so a volumetric zone-based risk integration methodology is used to account for this uncertainty.

In contrast, surface damage is present only on the exterior surfaces of a component and is often located at features (e.g., boltholes) or along other machined surfaces. Additional crack geometries were introduced in the DARWIN 4.x releases to model surface features. A feature-based methodology is used to estimate risk in which the disk risk is approximately equal to the sum of the risks associated with the individual features. For a typical disk, the number of features associated with surface damage assessment is relatively small compared to the number of zones associated with inherent defect-based assessment.

The initial framework for surface damage-based risk assessment is shown in figure 1. The user can define a mission profile and crack geometry for each surface feature in the disk. Included in the mission profile definition are the stress, temperature, and stress gradient values at discrete time steps.

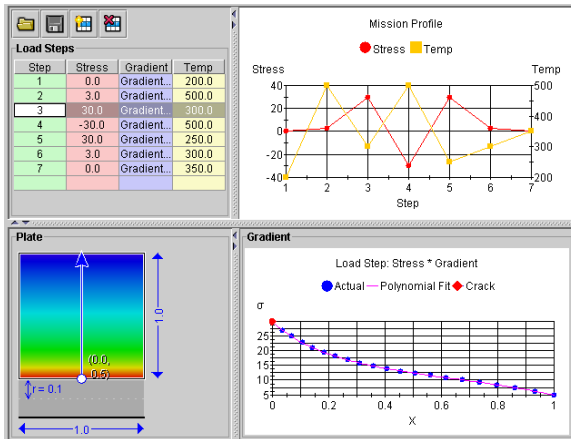


Figure 1. The Initial Framework for Surface Damage in DARWIN (Version 4.0) Includes a Mission Profile Consisting of Stresses and Temperatures at the Crack Location for Each Surface Feature

A number of enhancements were added in the recent 4.2 code release, including PC and Linux versions, the capability to execute the analysis code directly from the GUI, and improved deterministic crack growth assessment and visualization. A capability for modeling surface damage based on three-dimensional finite element geometry is currently under development for the 5.0 release (figure 2).

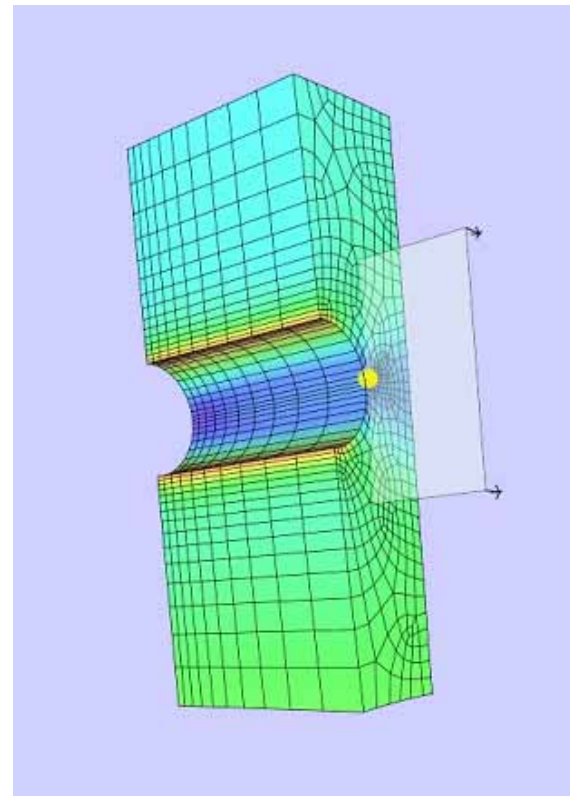


Figure 2. Capability for Modeling Surface Damage Based on Three-Dimensional Finite Element Geometry is Currently Under Development for DARWIN 5.0

Joseph Wilson, AAR-460, (609) 485-5579

## Propulsion Indications Research

A leading cause of propulsion-related accidents and incidents is propulsion malfunction, resulting in undesired crew response. The initial FAA response to this causal factor was to develop training materials that educate the crews for what to expect during rare propulsion malfunction events in flight. In 1995, a DC-10 crew rejected takeoff after hearing what they thought was a bomb exploding. The noise was, in fact, a high-power engine surge, see figure 1.



Figure 1. Rejected Takeoff After Surge

The Aircraft Catastrophic Failure Prevention program is evaluating new technologies that can take the current data available to the pilot, in the form of cockpit gages, and turn it into information and annunciations that direct the crew to the proper procedure when action is required. These reactions to an existing malfunction in flight are necessary to improve a pilot's ability to manage the propulsion system malfunction. For example, when a blade separates from the engine, a surge can occur followed by high vibration, as shown in figure 2. Additional long-term research is being considered to develop technologies that could identify when an engine has a high probability of malfunctioning and provide maintenance prior to the in-flight event. The complexity of engine operation makes the prognostic evaluation very challenging.



Figure 2. Accident Engine Missing a Fan Blade

Current research is being performed by Boeing Phantom Works to review the 1998 Aerospace Industries Association (AIA) accidents and incidents report in greater detail and add any subsequent events to the study. This effort specifically asks the question whether annunciation may have helped the crew and assesses the feasibility of technologies to reliably provide an indication. The work is supporting the AIA

Propulsion Indications Task Team. Rulemaking in this area has been put in moratorium, AIA plans to petition for rulemaking based upon the final report.

The current work is focused on information rather than individual gage data points. The study has teamed propulsion engineers, flight deck engineers, and human factors to take a global look at propulsion indications in the cockpit (see figure 3), and how pilots become aware of engine malfunctions. Actual event data was provided to evaluate the ability to detect a meaningful surge.



Figure 3. Modern Flight Deck

The research program has expanded on the original AIA event study and concluded that these propulsion malfunction and inappropriate crew response events are still occurring. The work added 11 new events, bringing the total to 91 events. The work categorized the malfunctions and phase of flight to develop a set of potential alerts that addressed the various malfunctions and developed a simulation in the B777-fixed base simulator. Analysis of events and real event data indicates that technology to provide indications in a meaningful amount of time to aid the pilot is feasible. Additional research is required to develop the systems and validate the safety benefits.

William Emmerling, AAR-460, (609) 485-4009

## On-Aircraft Engine Disk Crack Detection

On-aircraft disk crack detection research seeks to develop technologies (made available by the significant advances in computational and communications technology) that can identify a crack in a turbine engine disk in flight prior to failure. Under the Aircraft Catastrophic Failure Prevention Program, the initial focus of this effort is on fan disks.

The FAA initiated discussions with the Department of Defense and NASA to review the status of engine failure detection technologies, with specific interest in fan disk failures. In a November 2000 meeting at Naval Air Warfare Center (NAWC) Aircraft Division, Patuxent River, MD, with technology developers, it was clear that successes had been achieved in the laboratory, and that various technologies held promise. The overwhelming desire of the technology developers was to obtain data from a full-scale engine test. In April 2001, the FAA Uncontained Engine Failure Technical Community Review Group agreed to provide a full-scale test. The Naval Air Systems Command, FAA, U.S. Air Force, and NASA Glenn Research Center teamed up, in what could be considered a model application of collaboration, to explore and develop promising technologies to detect cracks in on-aircraft turbine engine disks in real time.

Testing was completed at the NAWC Weapons Division China Lake Survivability Laboratory on a NAWC-supplied TF-41 turbine engine, shown in figure 1. Four thousand four hundred and seventy-four cycles were completed to propagate an embedded fault in the fan disk shown in figure 2. The data generated will provide valuable insight to advance the state of the



Figure 1. Engine Test Facility

art in disk crack detection techniques. Previous disk crack detection testing has been conducted in a spin pit, but this is the first time a crack has been propagated in a full-up engine test. The full-up engine environment provides additional challenges in the form of real interactions from the environment and additional engine stages.



Figure 2. Instrumented Fan Disk

The FAA's investment in the demonstration test, along with NAWC China Lake providing the engine, resulted in a cost-effective demonstration of technologies. A significant effort was invested in the development and propagation of the fault prior to testing in the engine. This included analysis (figure 3), electron discharge

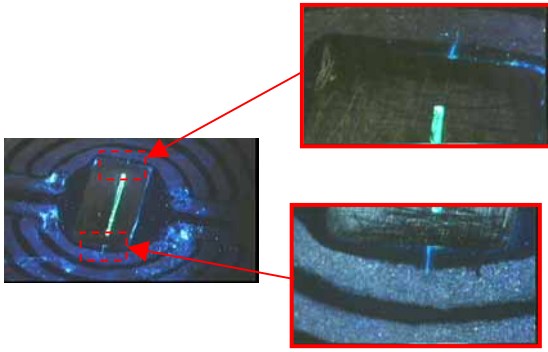


Figure 3. Finite Element Analysis of Crack

machining, and initiation of the crack under laboratory conditions to maximize the confidence that the crack would propagate during the short full-scale test. Inspection of the disk after spin-pit testing is shown in figure 4. Seven technology developers participated in the test. Technologies being explored included acoustic emission, crack wire mesh indicators, vibration, and proximity measurement to detect of the

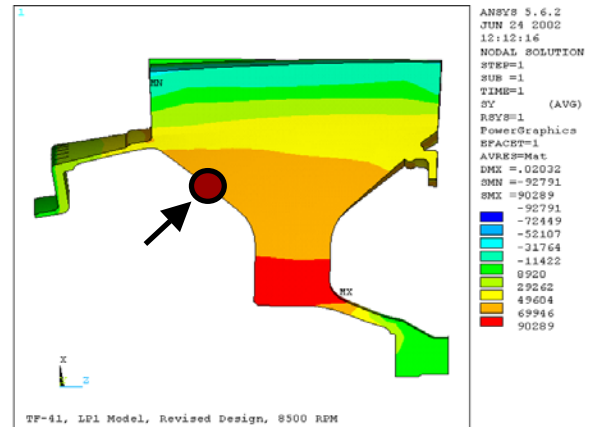


Figure 4. Crack Growth Inspection

change in the disk as the crack grows. This demonstration has created a cornerstone for government collaboration in aircraft safety research to pursue on-aircraft engine disk crack detection technology development.

William Emmerling, AAR-460, (609) 485-4009

## Uncontained Engine Debris Damage Assessment Model Version 2.0.2 Released

Naval Air Warfare Center Weapons Division (NAWCWD) China Lake and their support contractor, Survice Engineering Company, delivered version 2.0.2 of the Uncontained Engine Debris Damage Assessment Model (UEDDAM) for compliance with proposed revision to AC 20-128, which is currently in development by FAA ARAC.

Figure 1 shows a typical engine disk failure debris layout. Figure 2 shows how a typical spray pattern of debris would exit a turbine engine from a compressor disk failure.

In February 2003, a training session took place for the ARAC to familiarize airframe

and engine manufacturers with version 2.0.2 of the model and solicited comments.



Figure 1. Fan Disk Failure Debris

NAWCWD China Lake and Survice Engineering assembled the user's manual, briefing materials, and generic examples that took the group through the computer program in a very detailed lesson. Modeling

tools were used to analyze a simplified airplane to give all participants experience using the analysis features.

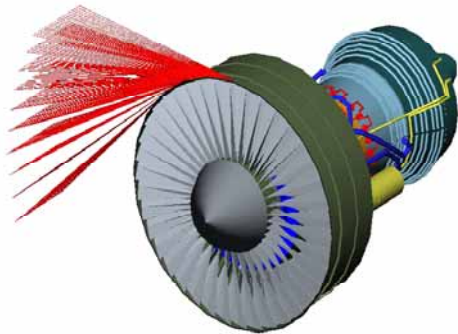


Figure 2. Engine Failure Model

The tool uses a Monte Carlo analysis to analyze the hazard to the airplane in accordance with the rotor burst guidance. The analysis can randomly simulate fragment impacts like a real event and repeats the analysis many times to develop the probability of hazard.

Bombardier completed their assessment and provided a favorable written report to ARAC that includes recommendations for improvement.

The UEDDAM vulnerability assessment tools automate the analysis and allow trade-off studies to be performed. This enhances

the safety of commercial aircraft by providing the means to critically examine the threat posed by uncontained engine debris and allows steps to be taken to mitigate the threat. Figure 3 shows a computer model from an analysis.

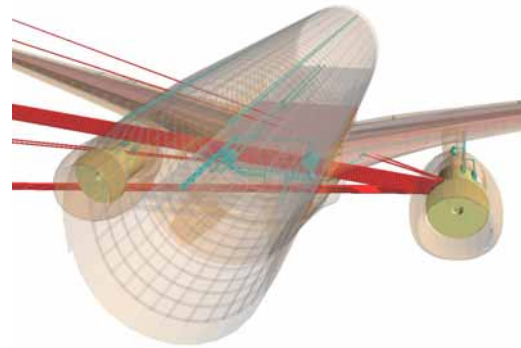


Figure 3. UEDDAM Disk Burst Analysis

The uncontainment research effort has produced several reports that are the result of years of effort in support of developing the revisions to AC 20-128, "Design Precautions for Minimizing Hazards to Aircraft from Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure." A revised compact disc containing all the reports was distributed at the 32<sup>nd</sup> ARAC meeting in November 2002.

Donald Altobelli, AAR-460, (609) 485-5940

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### **Technology Transfer of High-Strength Fabrics for Ballistic Protection of Flight-Critical Components From Uncontained Engine Failures**

Over the years, several civil aircraft accidents with catastrophic consequences have occurred when fragments from in-flight engine failures damaged critical aircraft components. To reduce the

probability of such incidents in the future, the FAA sponsored research to develop and apply advanced technologies and methods for mitigating the effects of uncontained engine bursts. These materials would not stop the largest fragments, like the compressor disc segment from the Sioux City accident. However, the loss of all hydraulic systems in that accident was attributed to smaller debris liberated by the failure rather than a direct hit by the large piece. In support of this FAA objective, SRI

International completed a research program to evaluate the ballistic effectiveness of fabric structures made from advanced polymers and has developed a computational ability (using the DYNA-3D model developed at Lawrence Livermore National Laboratory) to design fragment barriers. SRI focused on three commercially available high-strength polymer materials—PBO (Zylon), aramid (Kevlar), and polyethylene (Spectra). To allow the end user to design fabric barriers with reasonable computer time, SRI converted the detailed model to a simplified shell model, see figure 1.

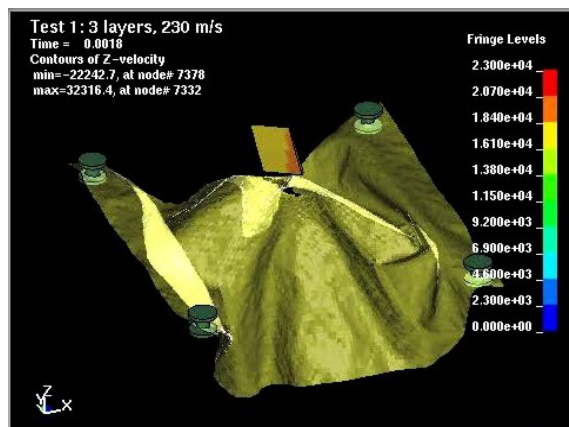


Figure 1. Simplified Model-Ballistic Simulation

The purpose of the current AACE program with the University of California-Berkeley (UCB) and Boeing is to transfer the technology from the SRI program to industry and determine the suitability of Zylon (which showed the most promise in the SRI work) as ballistic protection against uncontained aircraft engine fragments.

UCB completed small-scale ballistic testing of Zylon and Kevlar to verify the modeling techniques developed by SRI. Large-scale (actual blade fragment sizes) ballistic tests were completed by SRI that simulated the typical aircraft installations, as shown in

figure 2. Figure 3 shows an actual fan blade segment being stopped by the fabric barrier.

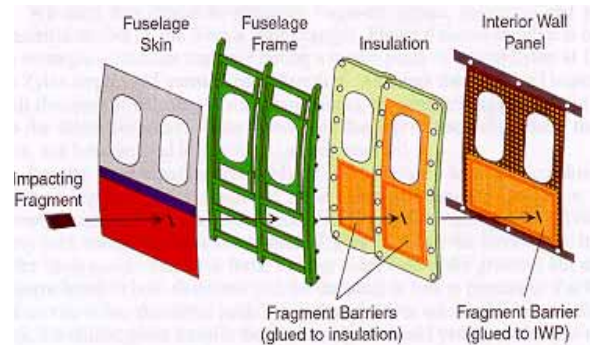


Figure 2. Armor Fabric Installation Schematic



Figure 3. Fan Blade Fragment Stopped in an Interior Wall Panel

Prior to the ballistic tests, modeling was done by SRI and UCB to predict the number of fabric layers necessary to stop the fragment. The predictions were very accurate when compared with the experimental data and resulted in a reduction of tests necessary to characterize the barrier protection.

Boeing conducted independent material development tests on Zylon to verify its strength and environmental impact on the material. All the testing and analysis will be documented in an FAA report.

Donald Altobelli, AAR-460, (609) 485-5940

## **Technology Transfer of Multilayer Composite Fabric Modeling for Gas Turbine Engines Containment Systems**

The purpose of this research effort is to use the FAA-funded fabric material model for aircraft barriers developed by SRI International in the design of engine containment barriers. A generic containment model has been developed by Honeywell Engines to assist industry in using this modeling tool for engine fabric containment predictions. In addition, the intention is to help standardize the methods for analysis so FAA Engine Certification engineers can make better judgments on new engine containment designs.

Arizona State University has completed quasi-static testing on Zylon and Kevlar materials on an engine containment ring configuration and built a containment ring model for Honeywell.

NASA-Glenn Research Center (as part of their engine containment program) has conducted several ballistic tests in their gas gun facility in support of this program. These tests were simulated by Honeywell using the material models supplied by SRI. The data from this testing has been the basis for the generic model developed by Honeywell.

Results will be documented in an FAA technical report to be released next year.

In August 2003, SRI and Honeywell presented a training course on the currently developed model to FAA Engine Certification engineers.

Donald Altobelli, AAR-460, (609) 485-5940

# Crashworthiness



## ATR42 Impact Test

On July 30, 2003, the FAA conducted a vertical impact test of a high-wing regional commuter airplane. The test was conducted at the FAA William J. Hughes Technical Center. The objective of the test was to evaluate the impact response of the fuselage, floor tracks, seats, and anthropomorphic test dummies on a large high-wing regional commuter airplane when subjected to a severe, but survivable, impact. An ATR42, a 42 passenger twin-engine turboprop, high-wing airplane (figure 1) was dropped from a height of 14 feet above the ground and impacted the surface with a final velocity of 30 feet per second. This is consistent with the vertical velocity change found in the Seat Dynamic Performance Standard 14 CFR Part 25.562(b)(1). The airplane was configured to simulate a typical flight condition, including seats, simulated occupants, simulated fuel, and cargo. The data collected in this test will supplement existing data and help provide the basis for future dynamic seat certification standards for commuter category airplanes. This is the last in a planned series of commuter airplane tests conducted by the FAA.



Figure 1. ATR42-300—Pretest

The airplane had a wingspan of 81 feet, weighed approximately 35,000 pounds, contained approximately 9000 pounds of simulated fuel (water), and 2100 pounds of luggage. The plane was configured with two simulated engines. Seven instrumented anthropomorphic test dummies and sixteen mannequins represented the crew and passengers. The airplane contained three different types of seats: the standard ATR current-generation seats, a 16-g-rated experimental seat, and an experimental energy-absorbing seat.

The airplane sustained substantial structural damage, especially at the fuselage/wing mating area of the cabin (figure 2).

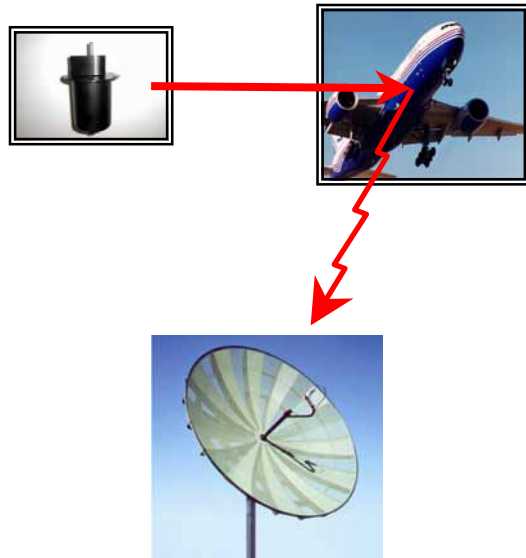


Figure 2. ATR42—Posttest

The test was well attended by Technical Center employees, the general public, the aviation community, and by local, state, and federal officials. There was extensive media coverage at the local, national, and international level in the newspapers and on television.

Allan Abramowitz, AAR-450, (609) 485-5885

# Safety of Flight



## Downlinking Icing Data From Commercial Aircraft

An ice detector warns a pilot when his or her aircraft encounters icing conditions. Some icing encounters are very hazardous and all have a potential effect on aircraft flight safety. If information concerning an icing encounter on one aircraft could be provided in near real time to weather forecasters and other aircraft, the pilots of other aircraft might be able to avoid potentially hazardous icing conditions. Also, archived data from icing encounters will be used in the evaluation and modification of current icing forecast models, which will contribute to the development of better models. The archived information can also be analyzed to develop a better understanding of how often aircraft encounter icing and where the encounters most frequently occur.

The FAA has joined with Goodrich Aerospace to investigate how to capture ice detector information from commercial aircraft. The approach that has been chosen is to downlink icing data from ice detectors mounted on commercial aircraft to ground stations, as shown in figure 1. Electronic uplinking would be a very efficient way of providing the data to other aircraft. It was decided that it would be best to start with a downlinking demonstration project using commercial aircraft that required minimal modification to its hardware and software, thus minimizing engineering and certification costs. A survey of aircraft in the commercial fleet was completed to determine which aircraft would be most appropriate for the project according to these criteria. The survey found that there are several types of aircraft that could downlink ice detector information with relatively minor hardware and software changes, but these changes would require some hardware engineering and certification work.

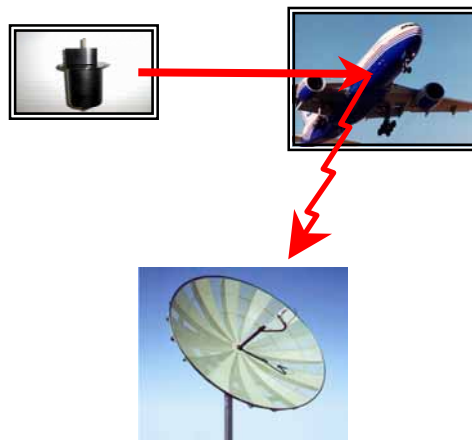


Figure 1. The Ice and No-Ice Signal From the Ice Detector Mounted on the Aircraft is Transmitted to a Ground Station

However, the B777 was found to only require a software modification, without additional certification, to downlink the ice detector information. The software modifications were coded, and several airlines were contacted to see if they would participate in this project.

Delta Air Lines was the first to participate in the demonstration project and is currently downlinking icing data from the ice detectors on its entire fleet of B777 aircraft. Downlinking icing data started during the 2002-2003 winter icing season and will continue for 1 year. The resulting data is being provided to the National Center for Atmospheric Research in Boulder, Colorado, for use in the evaluation and enhancement of icing forecasting models. The potential safety value of providing such information in near real time to other aircraft will also be assessed. Results thus far look promising. A second airline has expressed interest in joining the project for the next winter season. Once the technical and economic feasibility of downlinking icing data from commercial aircraft has been established by this project, it is hoped that the airlines will participate in downlinking

icing data on a routine basis. Participation by regional carriers, which spend quite a bit of time in icing conditions, would be particularly valuable. Broad participation by commercial carriers would lead to the

improvement of icing forecasts and to the expansion and improvement of icing information available to pilots.

James Riley, AAR-470, (609) 485-4144

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## **Continuing Analysis Surveillance System Research Project**

Since 1964, all air carriers have been required by regulation to conduct continuous evaluations of their maintenance programs. Specifically, 14 CFR Parts 121.373 and 135.431 require air carriers to establish a Continuing Analysis and Surveillance System (CASS) to evaluate, analyze, and correct deficiencies in the performance and effectiveness of their inspection and maintenance programs. These regulations do not distinguish between maintenance functions the air carrier accomplishes and those that it contracts out. Nevertheless, the responsibility for CASS remains with the air carrier.

CASS is an air carrier quality assurance system and must consist of the following functions: surveillance, controls, analysis, corrective action, and follow-up. Together, these functions form a closed-loop system that allows the air carrier to monitor the quality of its maintenance. In a structured and methodical manner, CASS provides air carriers with the necessary information to make decisions and reach their maintenance program objectives. Furthermore, if CASS is used properly, it becomes an inherent part of the air carrier's way of doing business and helps promote a safety culture within the company.

While the regulation governing CASS is short and offers little guidelines, its sparse language nonetheless requires a complex system. Each CASS must set high goals, and the FAA is empowered by the

regulations to require changes to an air carrier's maintenance program if it shows signs of weakness.

To help industry maintenance personnel and FAA inspectors understand and comply with CASS requirements, the FAA Flight Standards Aircraft Maintenance Division (AFS-300) asked the Risk Analysis Branch (AAR-490) to conduct research on CASS requirements in December 2001.

AAR-490 completed the research in October 2002. Three models were developed that illustrate how the structure of CASS can be established based on the air carrier's size and complexity. CASS model 1 is for large 14 CFR Part 121 air carriers with more than 100 turbine-powered aircraft operating worldwide, model 2 is for 14 CFR Part 121 or 135 air carriers with 5 to 20 turbine-powered aircraft operating in a domestic regional network, and model 3 is for air carriers with fewer than five turbine-powered aircraft of ten or more seats operating on demand under 14 CFR Part 135. Each model represents a complete system that should meet, or exceed, the regulatory requirements. Existing air carriers can also use the models as a comparison to their existing CASS and determine its effectiveness. A new entrant carrier can use one of these models to establish its CASS.

The research results are based on the information gathered through research and on-site interviews with industry, FAA, and trade association representatives. Interviews with eighteen 14 CFR Part 121 air carriers,

five 14 CFR Part 135 air carriers, four aviation industry associations, and a representative of the Joint Aviation Authorities of Europe were conducted over a 6-month period. Interviews of personnel at the FAA Flight Standards District Office, Certificate Management Office, and Headquarters were also conducted to gain input from the regulatory perspective.

Based on the research materials, AFS-300 developed the advisory circular “Developing and Implementing a Continuing Analysis and Surveillance System,” AC 120-79, which was approved April 21, 2003. Following the AC’s guidance is one method of complying with the requirements of 14 CFR Parts 121.373 and 135.431.

Michael Vu, AAR-490, (609) 485-8143

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## FAA Certification Issue Paper Study

During the design certification of new aircraft, the Aircraft Certification Service uses a system of issue papers (IPs) to document the decision-making process on new, novel, and unique certification issues. This process has been used since the early 1980s. Hardcopies of the IPs have been used for the last 15 years, and the majority of IPs have been addressed through regulations. The 1500 IPs generated over the last 6 years have been stored electronically by project, but no attempt has been made to recover the historical and managerial information they contain. These IPs contain information concerning

- potential revisions to 14 CFR Part 25 (Transport Category Airplane),
- areas where existing policy and guidance are inadequate, and
- technical subjects, which are resource-intensive.

The FAA Certification Issue Paper Study was a research effort to review certification issue papers that were generated in the past 6 years and to develop methods of sorting and evaluating this data would allow the Transport Airplane Directorate to process the information in a more efficient way.

The FAA Issue Paper Database Application (figure 1) is a user interface to the IP database. The application was designed in a Microsoft Access environment. This interface has three groups of operations: forms, reports, and queries. The description of each group is explained below.

**Forms:** Through forms, users can enter new IP data into the system. Users are required to pick from a preset classification, keywords, type of IP, aircraft, and enter other information such as the subject, project, regulation, and the executive summary. There is a provision to hyperlink to the actual IP so users can open the IP document.

**Reports:** The application can generate reports on the IP database for classifications such as Airframe, Cabin Safety, Flight Test, Propulsion, and Systems. The reports present information on keywords, manufacturer, type of aircraft, and the issue description related to the selected classification.

**Queries:** The application allows users to query the IP database based on keyword, IP type, classification, applicant, aircraft model, IP status, and regulation. All the results of the query have hyperlinks to the IP document. There is a provision in the application to view the entire database.

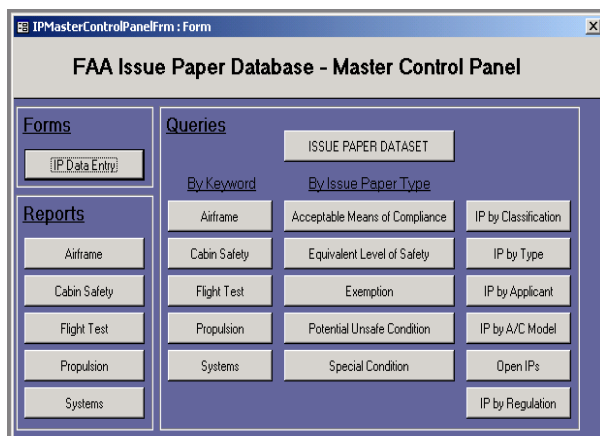


Figure 1. Master Control Panel Screen Layout

Of the over 2000 FAA IPs screened and reviewed, 1167 unique IP records were categorized and entered into the newly created FAA IP database. These records (and all records that may be added in the future) are available for review and development of trend analysis as needed by the certification engineers in the Transport Airplane Directorate. The FAA Issue Paper Database Application provides a simple means of organizing and analyzing certification issues to assist the Transport Airplane Directorate in managing those issues.

Cristina Tan, AAR-490, (609) 485-8168

## Effects of Mixed-Phase Icing Conditions on Aircraft Surfaces and Aircraft Thermal Ice Protection Systems

Most aircraft icing in the atmosphere is due to supercooled liquid droplets (droplets at temperatures below 32°F) impinging and freezing on aircraft surfaces. However, many clouds are mixed-phase clouds, containing both supercooled droplets and ice particles. The safety of flight into mixed-phase clouds has been a long-standing question, with limited scientific information available on which to base sound engineering decisions. Most information on in-flight icing is for purely liquid clouds, and certification requirements are written for those conditions. The National Transportation Safety Board has recommended to the FAA that aircraft icing certification requirements be expanded to include mixed-phase icing conditions if necessary, and the FAA has investigated questions bearing on the magnitude of the safety threat that may be posed by mixed-phase conditions.

The FAA determined that testing in an icing tunnel was needed, and a test was conducted in the Cox & Company Icing Wind Tunnel in July 2002 using a wing section equipped with a thermal ice protection system. Analysis of the test results was completed and a report, "Assessment of Effects of Mixed-Phase Icing Conditions on Thermal Ice Protection Systems," DOT/FAA/AR-03/48, Al-Khalil, K., was published in May 2003. This was a collaborative effort involving the FAA, Wichita State University, Cox & Company, and NASA Glenn Research Center.

The test results indicated that in mixed-phase icing conditions, ice accretion resulted mainly from the supercooled water droplets present in the mixed-phase cloud. For glaze ice, which occurs at temperatures close to 32°F, the ice particles in the mixed-phase clouds actually reduced the overall size of the ice accretion, as shown in figure 1.

It is believed that this may have been mainly due to shedding or splashing of water from a surface water film due to ice particles bounced in the film and, to a lesser extent, due to erosion of accreted ice by the incoming particles.

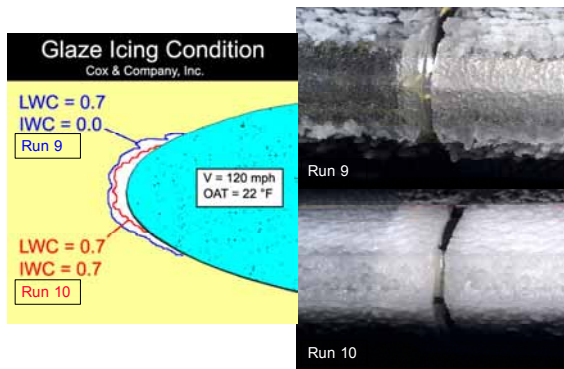


Figure 1. Comparison of Glaze Ice Accretions in Purely Liquid and Mixed-Phase Conditions

The performance of the thermal ice protection system, when used in an evaporative mode (which evaporates all incoming water or ice), did not seem to be adversely affected by the presence of ice particles in the cloud. However, testing the system in a running-wet mode (which prevents freezing in the protected region, with water running back to a less critical area) showed that the power requirements at the leading edge were much higher when ice particles were present in the simulated cloud, as shown in figure 2. The bars indicate a cloud consisting entirely of water from the spray bars, but all other conditions

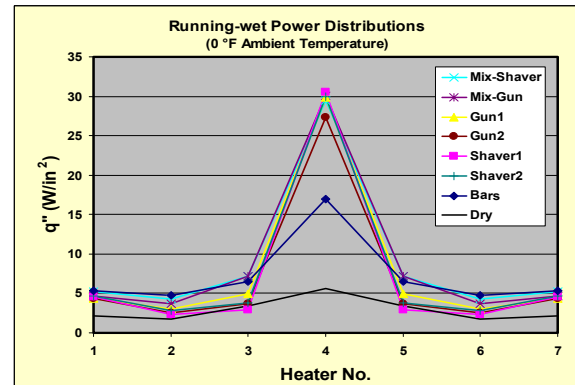


Figure 2. Power Distributions for a Thermal Ice Protection System in the Running-Wet Mode for Several Icing Conditions

are either mixed-phase or consist of ice particles only. Heater No. 4 is at the leading edge of the wing section.

This investigation used state-of-the-art simulation methods and visualization techniques that yielded unique data. Although the ice particles that can presently be simulated represent only a small percentage of the many types found in the atmosphere, the investigators believe that the trends observed in the tunnel will also occur during natural icing encounters.

James Riley, AAR-470, (609) 485-4144

## Modernizing Graphs on Aircraft Icing Design Criteria

Title 14 Code of Federal Regulations contains scattered graphs and tables of supplementary data or information, usually in the appendices to the various parts of the CFR. Some of this material would be useful beyond the original vision of the suppliers if the material were in a computer-compatible form so that graphs could be customized or data tables imported directly into computer programs. An example of the benefits of

computerizing a particular supplementary graph is illustrated as follows.

Appendix C of 14 CFR Part 25 contains six graphs of design variables that are frequently used by designers of in-flight ice protection systems, by data analysts for icing test flights, icing wind tunnel tests, and by computer modelers of ice shapes on aircraft surfaces. One of the most used figures from 14 CFR Part 25, Appendix C is reproduced in figure 1. This, and the five other companion figures, have been published in the CFR since the early 1960s.

Unfortunately, the published versions of some of the figures are of a poor quality, as shown in figure 1. The graphical grid spacing is awkward in that it is not evenly matched to the numerical scales marked along the axes. Also, these fixed (printed on paper) versions of the graphs are not convertible to other useful versions (R. K. Jeck, "Converting Appendix C to Other Variables," paper no. 2003-01-2153 in *Proceedings of the FAA In-Flight Icing/Ground De-icing International Conference & Exhibition* (Chicago, IL, June 16-20, 2003)).

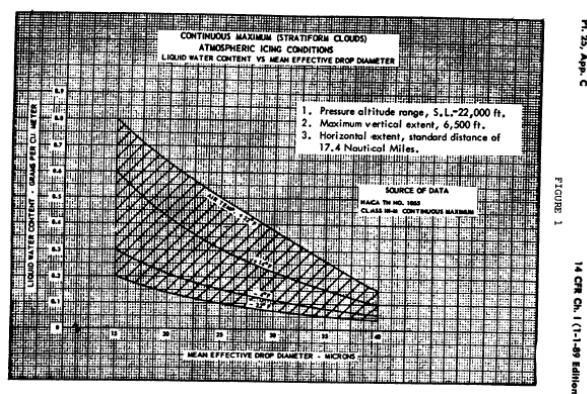


Figure 1. Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions (reproduced from 14 CFR Part 25, Appendix C)

These problems can be easily overcome by tabulating the coordinates of the curves in figure 1 in a computerized spreadsheet. Then, using the charting capabilities of the spreadsheet software, clean, properly scaled reproductions of the original graphs can be produced at will, as shown in figure 2.

The advantages of spreadsheet-based graphs in this example are that they

- have a cleaner, sharper appearance than the printed versions in the CFR.

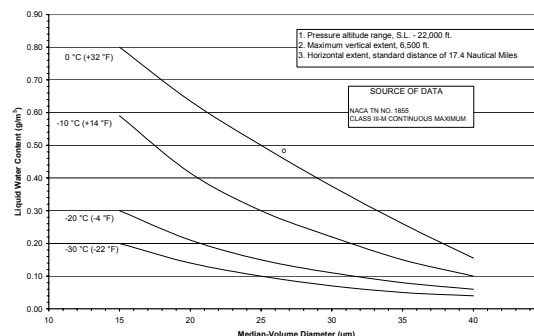


Figure 2. Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions (produced using spreadsheet software)

- have a more convenient grid spacing on the vertical and horizontal axes than the printed versions in the CFR.
- are easier to size and insert electronically into word processors or other computerized documents.
- can be adjusted or customized to suit the needs of various applications.
- can be converted to other useful variables or scales.
- can replace the original graphs with cleaner, better versions in the printed CFR.

In summary, common computer technology can be used to modernize supplementary material that is currently available only in hard copy form in the CFR. When the CFR is made available on compact disc or other computer-compatible media, working files such as spreadsheet versions of graphs can be included and supplied directly to the user to enhance the usability of graphical data.

Richard Jeck, AAR-470, (609) 485-4462

## Rocket-Triggered and Natural Lightning Research

The University of Florida's Lightning Research Laboratory has undertaken, under funding by the FAA, the task of characterizing electric and magnetic fields associated with very close lightning strikes. The characterization of the electric and magnetic field wave shapes, along with statistical analysis of salient wave shape features for initial and return or subsequent lightning strokes, is being carried out for two distinct cases: lightning triggered by use of a rocket-and-wire technique and natural lightning.

The University of Florida has analyzed the salient characteristics of the electric and magnetic fields and their derivatives at distances of 15 and 30 m from triggered lightning strikes. Return stroke current and current derivative characteristics were also determined. Measurements were made at the International Center for Lightning Research and Testing at Camp Blanding, Florida. Lightning was triggered to a 1- to 2-m strike object at the center of a 70- × 70-m metal grid ground plane that was buried beneath a few centimeters of soil. The strike object was mounted on a rocket-launching system located below ground level in a pit. The experiment was designed to minimize the influence of the strike object on the field and field derivative waveforms and to eliminate potential distortions of the field and field derivative waveforms both due to ground surface arcing and due to the propagation of the field being over imperfectly conducting ground. Measurements were made on about 100 return strokes, although not all field quantities were successfully recorded for each stroke. Figure 1 shows a rocket-triggered lightning experiment with multiple return strokes. The following waveform

characteristics were analyzed: current peak, rise time, and width; current derivative peak, rise time, and width; return stroke electric field change and field pulse width at 15 and at 30 m; electric field derivative peak, rise time, and width at 15 and 30 m; magnetic rise time and width at 15 and 30 m. The results were compared with those from previous studies.

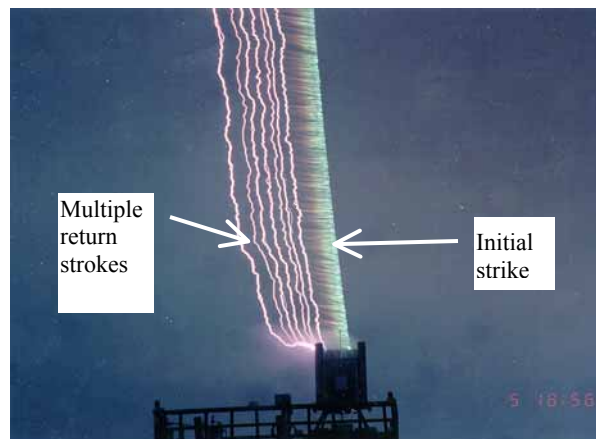


Figure 1. Rocket-Triggered Lightning Experiment With Multiple Return Strokes

To measure natural lightning strikes, an 11-station electric and magnetic field measuring network, covering 0.5 km<sup>2</sup>, was installed at the International Center for Lightning Research and Testing in 2002. The network is capable of taking 20 wide-band measurements distributed among the 11 locations. In summer 2003, five thunder measurements were added to the network.

Video coverage from four sites is used to help determine the location of the lightning within the network as well as the geometry of the lightning channel. Data have, thus far, been obtained for nine cloud-to-ground flashes (five during summer 2002, two during winter 2002-2003, and two during summer 2003) that terminated within the network. It is expected that in the 2 years following summer 2003, enough data will be

accumulated to provide meaningful statistics for the electric and magnetic fields of natural lightning, particularly natural first strikes (which do not occur in triggered

lightning), similar to those statistics discussed above for triggered lightning.

Anthony Wilson, AAR-470, (609) 485-4500

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## Experimental Study of Supercooled Large Droplet Impingement on Aircraft Surfaces

A major concern in the design and certification of ice protection systems for aircraft is the extent of supercooled water droplet impingement on aircraft surfaces, since this results in the formation of ice. The impingement characteristics of aircraft surfaces can be used to determine the size and location of ice protection systems. Droplet trajectory and impingement computer programs are often used as a cost-effective means for the design of ice protection systems. Current programs have been extensively tested for the icing conditions currently included in the FAA regulations. However, they have not been validated for supercooled large droplet (SLD) icing conditions, which are expected to be added to the FAA regulations soon. Consequently, the FAA determined that tunnel testing was needed to obtain experimental data that could be used for development and validation of droplet trajectory and impingement computer programs. A collaborative effort was undertaken involving Wichita State University (WSU), NASA Glenn Research Center (GRC), and the FAA. Testing was conducted by WSU under an FAA grant in the NASA GRC Icing Research Tunnel. A very extensive data set was obtained, which was then processed and analyzed by WSU. A final report was published: "Experimental Study of Supercooled Large Droplet Impingement Effects," DOT/FAA/AR-03/59, Papadakis, M., et al., September 2003.

The testing used a dye tracer technique that had been used in the past for measuring local impingement efficiency on aircraft aerodynamic surfaces. In this technique, water containing a small amount of water-soluble dye is injected in the form of droplets into the air stream ahead of the body by means of spray nozzles. The surface of the body is covered with blotter material upon which the dyed water impinges and is absorbed. At the point of impact and droplet absorption, a permanent dye deposit (dye trace) is obtained. The impingement limits are obtained directly from the rearmost dye trace on the absorbent material.

It was necessary to update this technique in various ways so it would be appropriate for testing in SLD conditions. The 12-nozzle spray system was expanded to 16 nozzles to provide the required cloud uniformity for the SLD cases. Extensive updates were made to the hardware and software of the laser and charge-coupled device (CCD) reflectometers used for the reduction of the raw impingement data. New calibration curves were developed for the laser and CCD data reduction systems.

Impingement data were obtained for four two-dimensional airfoils and an airfoil with two different simulated ice shapes. Cloud conditions simulated included median volume diameters (MVDs) of 11, 21, 79, 137, and 168 microns. (The MVD is a convenient representative droplet size for the cloud.) The first two conditions are covered by the current regulations, but the last three are SLD conditions.

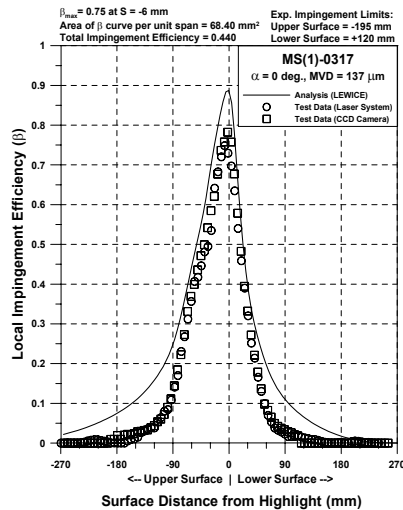


Figure 1. Experimental and Predicted Impingement Curves for an MS(1)-0317 Airfoil

Droplet trajectory and impingement computations were also performed with the computer program LEWICE. As shown in figure 1, a comparison of the experimental data to the computer results indicated that this program tended to overpredict droplet impingement in SLD conditions, especially in the tails of the impingement distribution. This suggests that modifications to LEWICE and probably other such programs will be necessary if they are to be sufficiently accurate to use for design and certification purposes.

James Riley, AAR-470, (609) 485-4144

## Portable Wireless LAN Device and Two-Way Radio Threat Assessment for Aircraft Navigation Radios

Under funding from the FAA, NASA Langley Research Center (LaRC) completed an assessment of the potential interference risk to aircraft radio systems from consumer wireless local area network (WLAN) devices and two-way radios.

Wireless technologies are widely adopted in the present consumer market. Technologies such as WLAN have brought a revolution in accessibility and productivity. WLANs

enable consumers to have convenient access to web browsing, email, instant messaging, and numerous enterprise applications (figure 1). As travelers become more dependent upon Internet access, airlines are increasingly interested in providing connectivity to their customers while traveling onboard aircraft. While WLAN equipment provided by the airlines for permanent installation on the aircraft must be properly certified, passenger carry-on products are not required to pass the rigorous aircraft radiated field emission standards, which may lead to increased risks of interference to aircraft radio systems.



Figure 1. WLAN Devices Used in RF Emission Measurements

Two-way radio communications, such as Family Radio Service (FRS) and General Mobile Radio Service (GMRS) (figure 2), are also becoming popular. These no-fee radio systems allow family members, friends, and business associates to stay in

contact during trips, shopping, or where party members may be physically dispersed. While use of these radios is not presently authorized on aircraft, passengers may use them anyway because of their low cost and popularity.



Figure 2. FRS and GMRS Two-Way Radios Used in RF Emission Measurements

Radio frequency (RF) emissions from portable WLAN devices and two-way radios were measured in NASA LaRC reverberation chambers (figure 3). In



Figure 3. Reverberation Test Chamber and a WLAN PC Card Installed in a Host Laptop Computer

addition, interference path loss (IPL) measurements were conducted with an airline partner to quantify the attenuation levels for emission from inside the passenger cabin. The IPL measurements were conducted on several commercial aircrafts, and the results compared with

existing data. The product of emission and path loss data was compared with existing aircraft radio interference thresholds to derive safety margins for interference risk assessments.

RF emissions in aircraft radio bands for several IEEE 802.11b, IEEE 802.11a, and Bluetooth WLAN devices from various vendors were measured. Emissions from FRS and GMRS two-way radios were also measured. The results were compared with emissions from laptop computers, Palm, and Window CE devices, which are currently allowed for use during noncritical phases of flight.

IPL measurements were used to assess the risks of interference to aircraft systems from passenger carry-on devices. IPL was measured for four B747-400 and six B737-200 aircraft during three 1-week trips to Southern California Aviation in Victorville, California. The airplanes were provided by United Airlines (UAL), and the measurements were conducted with the participation of UAL, Eagles Wings

Incorporated, and NASA LaRC. The measurements were conducted with a radiating antenna positioned at windows and doors, simulating emissions from passenger carry-on electronic devices, while a spectrum analyzer recorded the maximum signals coupled into aircraft antennas. The new IPL results were summarized together with the existing IPL data from other sources, which include references, standards, and results from previous NASA

cooperative efforts. Interference thresholds were summarized from an existing standard. The measured emissions, the overall IPL, and the interference thresholds were used to compute interference safety margins. The results will be documented in a report to be published next year.

Anthony Wilson, AAR-470, (609) 485-4500

# Fire Safety



## Minimum Performance Standard for Halon Replacement Agents for Aircraft Cargo Compartment Fires

The Fire Safety Branch, AAR-440, of the FAA William J. Hughes Technical Center published a technical note titled “Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems,” DOT/FAA/AR-TN03/6, Reinhardt, J., April 2003. This technical note establishes the minimum performance standard (MPS) that a Halon 1301 replacement aircraft cargo compartment fire suppression system must meet. It describes the tests that shall be performed to demonstrate that the performance of the replacement agent and system provides the same level of safety as the currently used Halon 1301 system. This MPS was developed in conjunction with the International Aircraft Systems Fire Protection Working Group, formerly known as the International Halon Replacement Working Group. In the past, the aircraft industry selected Halon 1301 total flood fire suppression systems as the most effective means for complying with the FAA regulations. Because of the ban on the production of Halon 1301 due to its harmful effects to the ozone layer (effective January 1994, as mandated by the Montreal Protocol), new fire suppression systems will need to be certified when Halon 1301 is no longer available.

The tests described in this standard are one part of the total FAA and Joint Aviation Authority certification process for cargo compartment fire suppression systems. Compliance with other applicable regulations is also required. Supplemental Type Certificate applicants attempting to certify replacement systems are encouraged to discuss the required process with regulatory agencies prior to conducting tests.

The results of these tests will be used to determine the required concentration levels to adequately protect an aircraft cargo compartment against fire and hydrocarbon explosions. Currently, the FAA Transport Airplane Directorate is developing a policy letter to address the certification of aircraft cargo compartment fire suppression systems employing halon replacement agents and recommend the use of this standard as part of the means of compliance.

There are four different MPS fire test scenarios that new cargo compartment fire suppression systems must meet: (1) bulk-load fire (Class A and C fire), (2) containerized fire (Class A and C fire), (3) flammable liquid fire (Class B fire), and (4) an aerosol can explosion (figure 1). The bulk- and containerized-load fires, which are deep-seated fire scenarios, use shredded paper loosely packed in cardboard boxes to simulate the combustible fire load. The difference between these two tests is that in the containerized fire load the boxes are stacked inside an LD-3 container, while in the bulk-load fire scenario the boxes are loaded directly into the cargo compartment. The flammable liquid test uses 0.5 U.S. gallon (1.89 liters) of Jet A as fuel. The aerosol explosion tests are executed by using an aerosol can simulator containing a flammable and explosive mixture of propane, alcohol, and water. This mixture ignites and causes an explosion within an enclosure when it is exposed to an arc from sparking electrodes. At least five tests per MPS scenario must be conducted. These tests are performed in a 2000 ft<sup>3</sup> simulated aircraft cargo compartment.

The suppression performance of a new agent, once the data is collected and analyzed, is then compared with the standard acceptance criteria to determine if acceptance criteria values are based on the it

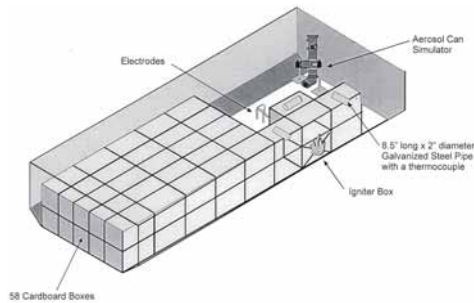


Figure 1. Example of an MPS Test Scenario—Aerosol Can Explosion Test

passes or fails the fire tests. The performance of Halon 1301. It is required that none of the peak temperatures and areas

under the time-temperature curves exceed the values specified in the acceptance criteria table.

The MPS discussed above replaces the standard reported in the technical report titled “Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems,” DOT/FAA/AR-00/28, Reinhardt, J., September 2000. In addition to gaseous replacement agents, the more recent MPS can be applied to nongaseous agents such as water or dry powder.

John Reinhardt, AAR-440, (609) 485-5034

## Development of an Onboard Inert Gas Generation System to Prevent Fuel Tank Explosions

During FY03, significant progress was made in the development of a practical and cost-effective inerting system to prevent fuel tank explosions. An inerting system reduces the concentration of oxygen in a flammable fuel mixture to a level that will not support combustion. Engine bleed air is passed through an air separation module (ASM), a device that separates air into two streams—nitrogen-enriched air (NEA) and oxygen-enriched air (OEA). A system developed by the FAA inertes the fuel tank with the NEA generated by the ASM and discharges the OEA overboard.

The FAA was challenged by industry to develop a practical and reliable system that could be installed on commercial airliners within the next several years. Previous onboard designs, developed and used by the military, were relatively heavy and experienced poor dispatch reliability, something that could not be tolerated by the airlines. Ground-based inerting was an improvement, but required an airport

infrastructure to supply nitrogen at each gate and a dedicated technician to transfer the nitrogen into the fuel tank, all at great expense. A simple concept was designed by FAA personnel. Fire Safety Branch personnel built a system from that design and ground tested it at the William J. Hughes Technical Center. The design incorporated a clever and relatively simple dual-flow design for generating NEA in flight. By using high-purity and low-flow NEA during ascent and cruise and lower-purity and high-flow NEA during descent, analytical modeling showed that most aircraft and flight regimes would render the fuel tank inert upon landing. Moreover, earlier experiments showed that the fuel tank would continue to remain inert while the aircraft was on the ground, negating the need for labor-intensive and costly ground operations. Industry was impressed by the relative simplicity of the design and the positive modeling results.

The Fire Safety Branch tested a small-scale fuel tank in a pressure vessel that could simulate the low pressures corresponding to various flight altitudes. The testing showed that the concentration of oxygen required to inert against a fuel tank explosion was

higher than previously thought, reducing the amount of NEA needed to protect the tank, significantly reducing the size and weight of the inerting system. In addition, simulated flight tests in an altitude chamber, initially on the ASM and later with a 1/4-scale model of a B747 center wing tank, provided favorable data that were consistent with the analytical model predictions. The 1/4-scale modeling tests mapped the distribution of nitrogen (actually measured reduced oxygen level), with time, throughout the 6-bay center wing tank over entire flight regimes. The combination of analytical model predictions, the Fire Safety Branch's testing in the altitude chamber, and ground demonstration tests of the inerting system on the B747SP was enough to convince Boeing to pursue onboard inerting as a viable means of preventing fuel tank explosions.

On December 12, 2002, a major press conference was held for the national news and TV media at the FAA William J. Hughes Technical Center to highlight the recent significant progress in fuel tank inerting. The press was briefed by Nick Sabatini, AVR-1, and John Hickey, AIR-1, on the full scope of the FAA's program to protect fuel tanks. This was followed by a number of demonstrations. After viewing the installation of the inerting system in the pack bay area of the B747SP ground test aircraft, the media witnessed its operation from an instrumentation room containing a series of oxygen concentration analyzers that measure the state of the six center wing tank bays. Also, a small-scale fuel tank explosion was shown to the press in the pressure vessel facility, followed by an inerting test that prevented the explosion. Lastly, the altitude chamber tests with the 1/4-scale model of the B747 center wing tank were explained. The newspaper articles and TV coverage were generally positive, and Administrator Marion Blakey characterized the inerting system as a "major breakthrough."

In July 2003, Boeing began a flight test program to certify an onboard inert gas generating system (OBIGGS), which is based on the FAA design, on a B747 aircraft. The Boeing flight test program is being supported with instrumentation (as described in "A Description and Analysis of the FAA Onboard Oxygen Analysis System," DOT/FAA/AR-TN03/52, Mike Burns and William M. Cavage, July 2003) and personnel from the Fire Safety Branch. Boeing publicly announced their intent to begin installing OBIGGSs on B747 aircraft in FY05. The Fire Safety Branch also performed a joint flight test program with Airbus. Tests were conducted using a modified version of the FAA's B747SP system installed in the cargo bay of an A320 aircraft (figure 1). Fire Safety Branch personnel collected data using the specially designed instrumentation shown in figure 2. That data should lead to a greater understanding of OBIGGS and improvements in design.



Figure 1. OBIGGS A320 Flight Test System



Figure 2. FAA Fuel Tank Oxygen Monitoring System for the A320

William M. Cavage, AAR-440, (609) 485-4993

## A Model for the Transport of Heat, Smoke, and Gases During a Cargo Compartment Fire

Current regulations require that aircraft cargo compartment smoke detectors alarm within 1 minute of the start of a fire and at a time before the fire has substantially decreased the structural integrity of the airplane. Presently, in-flight and ground tests, which can be costly and time consuming, are required to demonstrate compliance with the regulations. A physics-based computational fluid dynamics (CFD) tool, which couples heat, mass, and momentum transfer, has been developed to decrease the time and cost of the certification process by reducing the total number of in-flight and ground experiments. The model was developed by Sandia National Laboratories (SNL) with funding provided by NASA from their Aviation Safety Program. The tool would provide information on smoke transport in cargo compartments under various conditions, therefore allowing optimal certification tests to be designed.

The CFD-based smoke transport model will enhance the certification process by determining worst-case locations for fires, optimum placement of fire detector sensors within the cargo compartment, and sensor alarm levels needed to achieve detection within the required certification time. The model is fast-running to allow for simulation of numerous fire scenarios in a short period of time. In addition, the model is user-friendly since it will potentially be used by airframers and airlines that are not expected to be experts in CFD. The physics of the code have been verified by SNL and validation experiments are ongoing. The validation experiments are performed at the FAA William J. Hughes Technical Center in actual aircraft cargo compartments that are

extensively instrumented to record smoke, temperature, heat flux, and gas species levels during the tests.

The fire source for the validation tests is a flaming block of a variety of plastic resin pellets that are heated and compressed. A length of nichrome wire is embedded with the resin block and is used to precisely control that rate of heat release from the burning resins. This flaming resin block is proposed as the standard fire for cargo compartment fire detection systems and has been submitted for a patent. Testing has shown the flaming resin block to be a very consistent and repeatable fire source. Initial validation tests show reasonably good agreement with the code predictions. The code has been slightly modified to account for heat transfer to the walls and ceiling of the cargo compartment, and more validation experiments are planned. Two technical reports documenting the results will be published next year. One report documents the properties of the smoke produced by the flaming resin block compared to the properties of artificial smoke previously used in certification tests. The second report describes the computational approach used in the code, the graphical user interface that was developed, and the initial validation test results. Figure 1 shows a flaming resin block, and figure 2 shows the inside of the B707 cargo compartment used for a validation experiment.



Figure 1. A Flaming Resin Block



Figure 2. The Inside of a B707 Cargo Compartment

David Blake, AAR-440, (609) 485-4525

## Fire and Flammability

The two stages of fire development are ignition and growth. If a fire ignites and grows quickly in an aircraft cabin, there may not be enough time for passengers to escape. The FAA and other government agencies have determined that the heat release rate of burning plastics is the best indicator of how fast the fire grows in compartments such as aircraft cabins, trains, and rooms. However, none of the tens of billions of pounds of flame-retardant plastic sold worldwide each year is tested for heat release rate. Instead, plastics are only tested for ignition resistance (flammability) by measuring the time it takes for material to self-extinguish after removal from a Bunsen burner flame. Consequently, nothing is known about whether, or how fast, a fire involving these plastics will grow to dangerous proportions.

The Fire Safety Branch, AAR-440, is studying the relationship between flame test performance and fire growth to better understand the fire hazard of plastics. In flame tests (figure 1), plastics are not forced to burn but may continue to do so after removal of the Bunsen burner if the sample's flame returns enough heat to the

plastic surface to sustain the burning process. In contrast, plastics in fires or fire calorimeters (figure 2) are exposed to radiant heat that forces them to burn at a rate that increases with external heat flux.



Figure 1. Bunsen Burner Test of Ignition Resistance



Figure 2. Fire Calorimetry Test of Heat Release Rate

FAA researchers hypothesized that—in the absence of external heating—a plastic will cease to burn if the rate at which heat is released by the flame at the tip of the sample is insufficient to continue the burning process. To test this hypothesis, the heat release rate of burning plastics needed to be measured without any external heating (i.e., the unforced heat release rate,  $HRR_0$ ) and compared to the results of Bunsen burner tests of ignition resistance. The FAA used two strategies to measure the unforced heat release rate of plastics: direct measurement of  $HRR_0$  in an isolated flame test and obtaining  $HRR_0$  as the zero heat flux intercept in a plot of heat release rate versus external heat flux measured, as shown in figure 3.

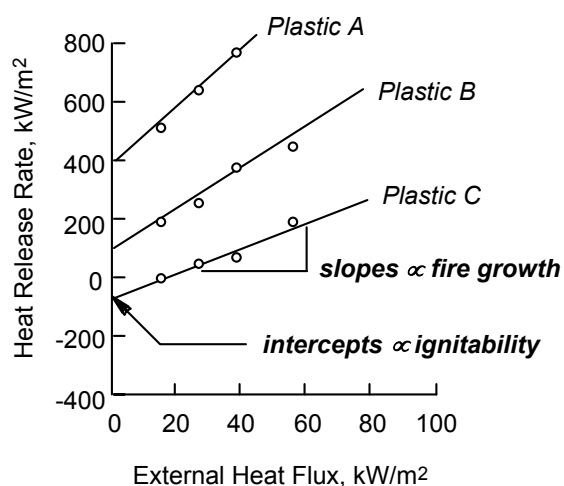


Figure 3. Typical Plot of Heat Release Rate Versus External Heat Flux Measured

Typical results for  $HRR_0$  obtained by the extrapolation method are shown schematically in figure 3 for three different plastics. Both the direct and indirect (intercept) methods gave comparable results for  $HRR_0$ . Separate tests were conducted to measure the ignition resistance of plastics in a flame test (figure 1) using standard procedures. Data from dozens of

commercial plastics and research materials were collected and analyzed.

The FAA found that plastics will self-extinguish when removed from a Bunsen burner flame if their release heat release rate in unforced flaming combustion  $HRR_0$  is below a critical value of about  $100 \text{ kW/m}^2$ . Figure 4 shows data for flammability rating in the Underwriters Laboratories Test for Flammability of Plastics (UL 94) versus  $HRR_0$  for over 40 different plastics. It is clear from figure 4 that self-extinguishing behavior (UL 94 V0 rating) is observed exclusively for plastics having  $HRR_0$  less than about  $100 \text{ kW/m}^2$ . Thus, both stages of fire development, ignition and growth, depend on the heat release rate, a quantity that is easily measured in a fire calorimeter (kilogram samples) or in the FAA's microscale combustion calorimeter (milligram samples). This result allows fire protection engineers and FAA regulators to better estimate the fire hazard of a plastic in a particular environment from a few heat release rate tests.

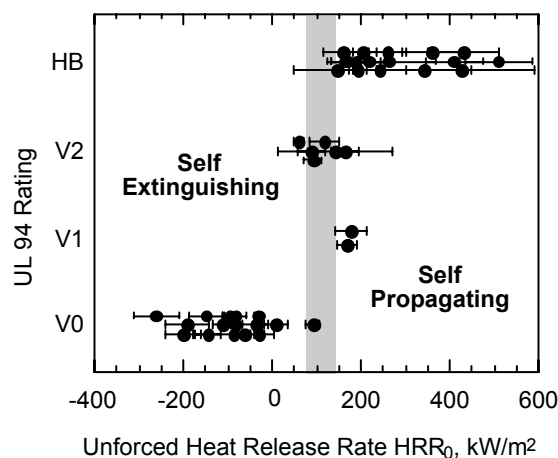


Figure 4. Ignition Resistance Measured in a Bunsen Burner Flame Test versus Heat Release Rate Intercept for 40 Plastics

Richard E. Lyon, AAR-440, (609) 485-6076

## Ground Tests of Aircraft Flight Deck Smoke Penetration Resistance

A technical note was published titled “Ground Tests of Aircraft Flight Deck Smoke Penetration Resistance,” DOT/FAA/AR-TN03/36, Blake, D., in April 2003. The report describes recent testing performed in support of an Aviation Rulemaking Advisory Committee harmonization working group using the Fire Safety Branch’s B747SP and B727 aircraft. The group was tasked with developing draft regulations and advisory material to implement an International Civil Aviation Organization (ICAO) agreement to include security considerations into the type certification of new aircraft.

One of the new requirements of the ICAO agreement was to include specific design features to prevent smoke and gases from entering the flight deck following the activation of an explosive or incendiary device anywhere in the aircraft except the flight deck itself. The threat from this scenario would be the smoke and gases from the ensuing fire. Ground tests were conducted in both aircraft to either measure or demonstrate the positive pressure differential between the flight deck and surrounding areas needed to prevent smoke penetration into the flight deck. Bleed air from the aircraft’s auxiliary power unit was used to run the air-conditioner packs, and every possible combination of each aircraft’s ventilation system settings was tested. An actual pressure differential was not directly measurable using a differential pressure gauge (figure 1) with a resolution of 0.005 inch of water (0.00018 psi) at any ventilation system configuration in either aircraft.



Figure 1. Differential Pressure Gauge

To test the positive and negative pressure differential, a thin sheet of plastic covering was installed over the flight deck door opening (figure 2). Enough plastic was used to allow the plastic sheet to deflect either forward or aft based on the airflow direction. When airflow into the flight deck of the B727 was maximized and the cabin airflow was minimized, the plastic sheet clearly deflected into the cabin area, indicating a positive flight deck pressure differential.



Figure 2. Plastic Sheet Installed Over the Flight Deck Door Opening

A theatrical smoke generator was then used to determine if this positive flight deck pressure differential was sufficient to prevent smoke penetration. The smoke generator was placed in the cabin of the B727 with the output nozzle pointing at the closed flight deck door approximately 8 feet away. The generator was turned on at its maximum output, completely filling the forward cabin section of the B727 with smoke. No smoke penetrated into the flight deck for this ventilation condition. These tests were repeated at every other ventilation system setting that did not cause the plastic sheet to deflect into the cabin area, and smoke penetrated into the flight deck in every case. Similar tests were conducted in the B747SP aircraft. None of the ventilation settings caused a deflection of the plastic

sheet into the cabin area in this aircraft, and smoke penetrated into the flight deck in every test regardless of the ventilation system settings.

The technique of using a plastic sheet to demonstrate the existence of a positive pressure differential and theatrical smoke generators to demonstrate the effectiveness of that pressure differential will be described in a new advisory circular as an acceptable method for complying with new regulations. The availability of functional test aircraft greatly enhances the Fire Safety Branch's ability to provide timely and realistic test results for FAA regulatory support.

Dave Blake, AAR-440, (609) 485-4525

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## **FAA Adopts Final Rule Requiring Improved Fire Tests for Thermal Acoustic Insulation**

The FAA adopted improved and new flammability test standards for thermal acoustic insulation used in transport airplanes (see Federal Register, July 31, 2003, pp. 45046 to 45084). The standards include new flammability tests for in-flight fire ignition resistance and postcrash fire burnthrough resistance. Both test methods were developed by the Fire Safety Branch, AAR-440. Earlier fire tests and aircraft service experience had shown that the current standards did not adequately address situations in which current insulation materials contributed to the propagation of a fire. The new rule will improve aircraft safety "by reducing the incidence and severity of cabin fires, particularly those in inaccessible areas where thermal acoustic insulation is installed, and providing additional time for evacuation by delaying the entry of postcrash fires into the cabin" (Federal Register, July 31, 2003, p. 45046).

The new test method for in-flight fire resistance is called the radiant panel test since it subjects a material heated by a radiant panel to a pilot flame (see figure 1). It gave a good correlation with large-scale fire test data. The pass/fail criteria require that any flaming not extend beyond a 2-inch length from the point of flame application or continue flaming after removal of the pilot flame. Most insulation cover materials that are currently in use, which are thin films, will not meet the new fire test criteria. For example, based on past tests, most Mylar films, particularly the metallized types, fail the test, as do many of the Tedlars. Kapton films are good performers, as was one metallized Tedlar, and would be compliant with the new criteria. However, other factors affect the flammability of the insulation film materials, including weight or thickness, scrim (reinforcing lattice) type and pitch, scrim adhesive, and use of flame retardants. Thus, it is expected that new film formulations will be developed now that the rule has been adopted.

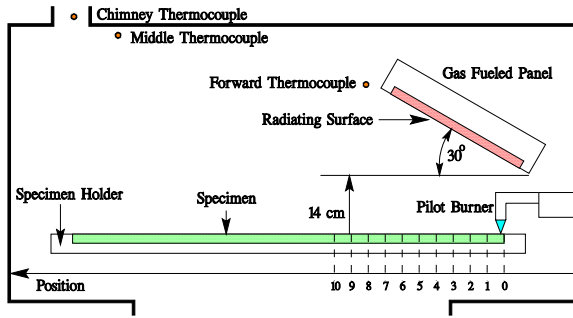


Figure 1. Schematic of Radiant Panel Test Apparatus

The test method for postcrash fire burnthrough resistance is a new test requirement since fuselage burnthrough resistance was not explicitly addressed in previous FAA regulations. It is comprised of two main components: a large burner that simulates a jet fuel fire and a sample holder representative of the fuselage structural framing (see figure 2).

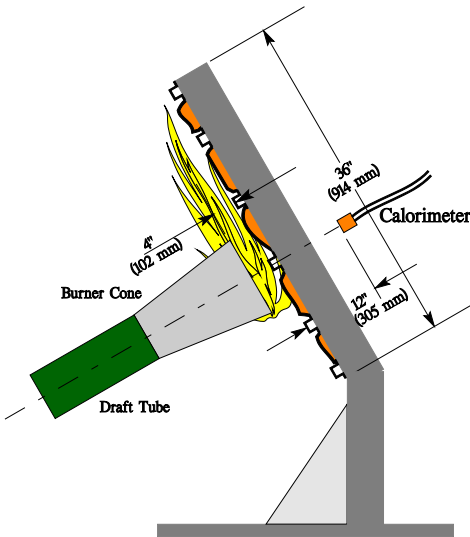


Figure 2. Proposed Burnthrough Test Apparatus

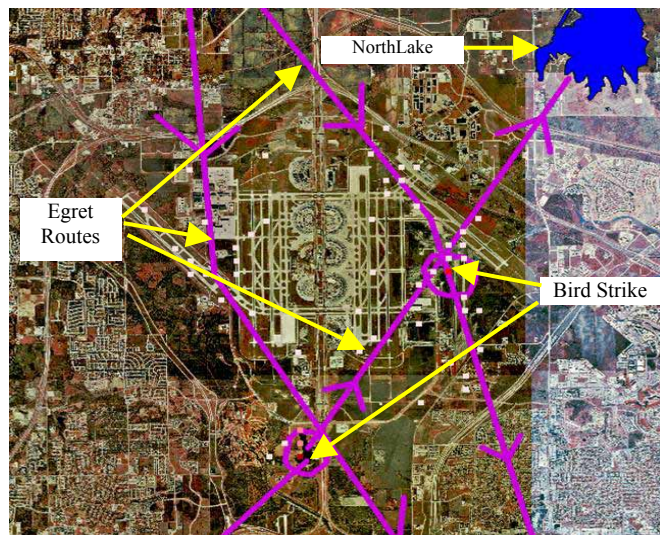
The burner flame conditions were set so that the melting time of aluminum sheeting would coincide with full-scale test results.

By analyzing past accidents, the required pass/fail criteria for the insulation specimen were set at 4 minutes because there would be very limited benefit beyond this period (i.e., approximately 5 minutes, factoring in the skin melting time). The burnthrough time is based on visual observation and measured heat flux through the specimen back face. The FAA has tested numerous samples submitted by industry, and many have passed the required criteria. Compliant specimens fall into three broad categories: advanced fibrous material (fiberglass replacement), fire barrier with existing fiberglass, and hardened film material.

Work is near completion for a planned advisory circular to support implementation of the new flammability requirements for thermal acoustic insulation. A standardized radiant panel test methodology is being finalized for the evaluation of tape and hook and loop (Velcro). Both are used extensively in the installation of insulation blankets, and torn blankets are repaired with tape. It has been found that both components can contribute significantly to insulation blanket flammability. In addition, the method of installing the blanket onto the fuselage framing has a critical effect on the degree of burnthrough resistance. Insulation blanket overlapping and using proper fasteners are required to gain full potential burnthrough protection. Factors affecting the effectiveness of fasteners (fixing methods) include composition (metal or plastic), through-insulation pins versus clamps, the pitch or spacing of the fasteners, and the proper attachment to a stringer or former.

Gus Sarkos, AAR-440, (609) 485-5620

# Airport Technology



## Repaint Criteria for Airport Surface Markings

The Airport Technology Research and Development Branch, AAR-410, has developed methods and equipment to help determine the effectiveness of airport surface markings and to establish standards to measure the need to reapply or restore airport surface markings. Paint markings on runways, taxiways, and ramps play an important role in preventing runway incursions. The visibility of paint markings, however, deteriorates over time, and they must be replaced. Presently, the visibility is determined by visual inspections of segments of these markings, but the validity of these inspections cannot always be confirmed.

This study was undertaken to develop a method for a quick and accurate evaluation of paint markings. A manual method was required to eliminate subjectivity in the current method, and an automated method was developed for evaluation of larger surface markings over a vast airport area. In addition, the study also established a threshold pass/fail limit for white and yellow paint.

For the manual method, three devices are required: (1) a retro-reflectometer is required for determining retro-reflectivity of the beads, (2) a spectrophotometer is required to determine whether or not the paint marking has faded out of tolerance, and (3) a transparent grid is used to determine coverage of the paint. If any one of these three tests failed, the pavement marking failed.

For the automated method, a van-mounted Laserlux or similar mobile unit is required. The automated method increases the speed and sample size. It works well for large airports that have very long runway centerlines and threshold markings.

The retro-reflective threshold limit for yellow paint is 70 mcd/m<sup>2</sup>/lx and for white paint 100 mcd/m<sup>2</sup>/lx. The coverage threshold pass/fail limit is 50%.

A summary of the results found during the evaluation was published in technical note “Development of Methods for Determining Airport Pavement Marking Effectiveness,” DOT/FAA/AR-TN03/22, Cyrus, H., March 2003.

Holly Cyrus, AAR-411, (609) 485-4887

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## Pavement Marking Research

The Airport Technology Research and Development Branch, AAR-410, has evaluated paint and bead durability in four areas: water emulsion paint performance, glass bead performance, application thickness of paint effectiveness, and cementitious pavement marking materials. A series of airport pavement markings were placed at the William J. Hughes Technical Center and the Atlantic City International Airport, Atlantic City, New Jersey, for evaluation. Results from the testing showed that HD-21A Rohm and Haas water

emulsion paint had superior performance since it held the beads in place better.

Type III (1.9 Index of Refraction (IOR)) airport beads had the best retro-reflectivity, initially and over time. All four new beads had higher retro-reflectivity than the 1.5 IOR highway bead but not as high as the 1.9 IOR airport bead. The four beads that were used in this study were 1.5 IOR Visibead A (L-511), 1.5 IOR Visibead B (L-511 Millennium), 1.5 IOR Megalux A (Airport and Highway High Quality and High Performance Drop-On), and 1.5 IOR Megalux B (Airport “Beacon” High Quality and High Performance).

The Lumimark cementitious pavement marking material evaluation was discontinued because the concrete mixture's shelf life was out of date, causing the concrete to flake. Immediately after installing this product, the beads sank into the cementitious material, causing very low retro-reflective readings. Therefore, the process still needs some refinement.

The PermaStripe cementitious pavement marking material, which is being evaluated by the U.S. Air Force and U.S. Army Corps of Engineers at Tyndall Air Force Base, is still under investigation and, therefore, not

ready for commercial application. At present, the PermaStripe product is hand applied with a squeegee. A paint hand-sprayer had been modified but is in the prototype stage. PermaStripe marking material also has very low retro-reflectivity readings.

A summary of the results found during the evaluation was published in "Paint and Bead Durability Study," DOT/FAA/AR-02/128, Cyrus, H., March 2003.

Holly Cyrus, AAR-411, (609) 485-4887

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## Taxiway Deviation Study

Within the next few years, several U.S. airports are likely to receive the Airbus A380. The airplane is categorized as a Design Group (DG) VI airplane and is the largest commercial airplane expected to serve the United States.

In AC 150/5300-13, "Airport Design," the FAA recommends the width of the straight section of the taxiway be 100 feet for DG VI aircraft. Most existing taxiway systems at affected airports, however, were built to DG V standards, with a recommended width of 75 feet for the straight section of the taxiway.

In an effort to mitigate impacts, the Airport Technology Research and Development Branch, AAR-410, conducted a pair of field data collection efforts focused on taxiway widths of straight sections. The multiyear efforts were conducted at John F. Kennedy International Airport, New York, and Ted Stevens Anchorage International Airport, Alaska, and measured the extent to which the B747 aircraft laterally deviated from the taxiway centerline during normal operational taxiing.

Under a cooperative agreement between the FAA and Boeing, a Boeing statistician used an extreme value statistical theory to analyze the data to determine if it would be possible to reduce the 100-foot taxiway width standard for all DG VI airplanes.

Based on preliminary analysis of AAR-410's collected data, the FAA determined that it is possible to safely allow the use of existing nonstandard 75-foot-wide straight taxiway sections by the A380 on an interim basis under specific conditions. In August 2003, the Airport Engineering Division, AAS-100, issued Engineering Brief No. 63, which specifies the conditions for this limited use.

The introduction of the A380 is expected to have a similar impact on other design standards in addition to taxiway widths, including separation of taxiway and taxilane from runways and clearances from fixed and movable objects. AAR-410 is conducting similar data collection efforts in the field to support the mitigation of these impacts.

Ryan King, AAR-411, (609) 485-8816

## Development of the Geographic Information System to Map and Mitigate Wildlife Strikes at Airports

In 2003, the FAA completed a Geographic Information System (GIS) for the Dallas Fort Worth (DFW) Airport. The WILD-GIS-DFW system was developed to centralize all wildlife records. It will be used as an operational and a research tool to mitigate wildlife strikes at the airport.

At DFW, the focus is on mitigating bird strike risks. As with most airports in the nation, DFW has a number of bird strikes every year. Some of these strikes are quite severe and create a major safety risk to aircrafts. It is known that bird populations have been increasing steadily over the last decade in North America. For some large birds, such as the Canada goose, very large increases have been observed. These large birds have already resulted in loss of life when striking aircrafts of all sizes.

WILD-GIS-DFW is an intelligent-mapping electronic system with a multitude of layers. These layers are used to map

- historical and current bird observations,
- reported bird strikes,
- observed bird routes,
- seasonal land use, and
- aircraft approach and departure corridors.

Figure 1 shows an example of the intelligent mapping with layers of information, in this case for egrets, where the reported bird strikes are superimposed on the observed bird routes.

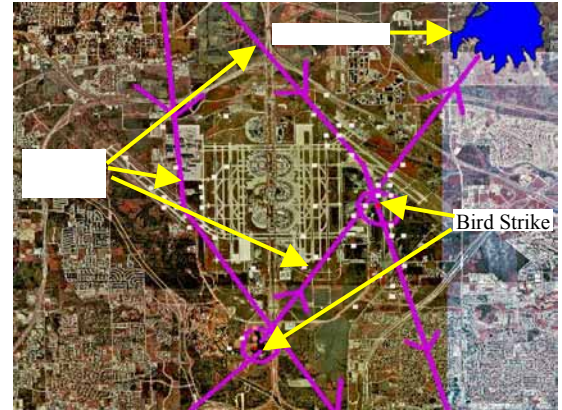


Figure 1. WILD-GIS-DFW Showing Strike Records and Egret Daily Routes

One of the critical parameters is time sensitivity. For instance, some birds only migrate along some routes at certain times of the day and night. Using this information, users can create bird hazard density maps for different times, days, and seasons.

As an operational tool, the system provides the airport with the ability to analyze bird density maps to estimate the risks to aircraft created by these various hazard levels. As a research tool, GIS layers can be turned on or off, giving the user the ability to research, identify, and analyze correlations between various pieces of data. For instance, one will be able to study seasonal land use against bird population density. At the regional planning level, the airport can then use the information to influence land use planning and development so that bird strike risks are mitigated over time.

Michel Hovan, AAR-411, (609) 485-5552